SOIL SCIENCE

Contents

SOIL SCIENCE

FOUNDED BY
RUTGERS COLLEGE
NEW BRUNSWICK, N. J.

EDITORIAL BOARD

NITRIFICATION IN SOILS

H. N. BATHAM

Department of Agriculture, United Provinces, India

INTRODUCTION

From the standpoint of soil fertility the nitrogenous portion of the soil is of undoubted importance. The major portion of the nitrogenous matter of soils is either composed of proteins or has been derived from proteins.

Recent investigations concur in stating that the chemistry of soil nitrogen is essentially the chemistry of proteins undergoing hydrolysis. Proteins find their way into the soil in the form of plant and animal debris, manures and fertilizers. As soon as these substances are incorporated in the soil, hydrolytic decompositions ensue.

The investigations of Shorey (23, 24), Jodidi (9), Robinson (17) Lathrop and Brown (11), and Kelley (10) on the classification of the nitrogenous decomposition products such as ammonia, mono-amino acids, and diamino acids, and the work of Schreiner and Shorey (19), Shorey (25), and Lathrop (12) on the isolation of a number of amino acids from soils indicate that in the process of decay of proteins in the soil they are split up along the same lines of cleavage, depending on the structure of the original molecule, be it through the agency of microörganisms, the agency of enzymes in digestion, or agents such as acids and alkalies in the laboratory. These simpler bodies, which are termed primary decomposition products, as proteoses, peptones and polypeptides, are no doubt formed in the soil (26) and are subject to still further decomposition through the same or other agencies. These secondary products are very numerous and are mostly amino acids of widely varying compositions.

Researches, thus far carried on, on the chemical constitution of the protein molecule, show that it is built up of a number of amino acids belonging to the following four different series (16).

I. Mono-amino-mono-carboxylic acid as:

α alanine $CH_3 \cdot CH(NH_2) \cdot COOH$

Leucine $\begin{array}{c} CH_3 \\ \diagdown \\ CH_3 \diagup \end{array} CH \cdot CH_2 \cdot CH(NH_2) \cdot COOH$

Tyrosine $HO \cdot C_6H_4 \cdot CH_2 \cdot CH(NH_2) \cdot COOH$

Cystine $HOOC \cdot CH(NH_2) \cdot CH_2 \cdot S \cdot S \cdot CH_2 \cdot CH(NH_2) \cdot COOH$

337

II. Mono-amino-dicarboxylic acid as:

Aspartic acid $HOOC \cdot CH_2CH\,(NH_2) \cdot COOH$

Glutamic acid $HOOC \cdot CH_2\,CH_2 \cdot CH(NH_2) \cdot COOH$

III. Diamino-mono-carboxylic acid as:

Arginine $HN = C \Big\langle \begin{matrix} NH_2 \\ NH \cdot CH_2 \cdot CH_2 \cdot CH_2 \cdot CH(NH_2) \cdot COOH \end{matrix}$

Lysine $H_2N \cdot CH_2 \cdot CH_2 \cdot CH_2 \cdot CH_2 \cdot CH(NH_2) \cdot COOH$

IV. Heterocylic compounds as:

Histidine

$$\begin{matrix} & CH & \\ N & & NH \\ CH = C & - & CH_2 \cdot CH(NH_2) \cdot COOH \end{matrix}$$

Proline

$$\begin{matrix} CH_2 & - & CH_2 \\ CH & & CH - COOH \\ & NH & \end{matrix}$$
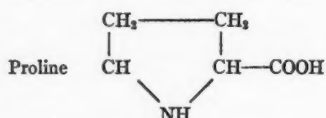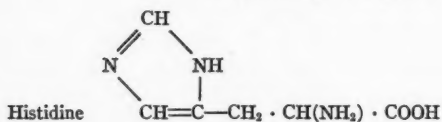
In addition to the above amino acids there are also found in the soil other groups of nitrogenous organic compounds such as:

1. Purine bases.
2. Pyridine group.
3. Pyrimidine derivatives.

It is a well-known fact that organic fertilizers are rapidly nitrified when placed in the soil under conditions favorable for the action of bacteria and fungi, but the accumulation of nitrates is not so rapid from them as from ammonium sulfate, simply because ammonia directly nitrified, whereas the organic nitrogen must first pass through a specific cycle of decomposition processes before undergoing ammonification and nitrification.

It has been shown by different investigators that ammonia (18) and a number of organic compounds (7, 20, 21) derived from the decomposition of proteins are of direct value in plant nutrition, but experiments in Europe and America appear to concede the paramount importance of the nitrate form of nitrogen for the nutrition of most plants (14).   Workers have, therefore, preferred to use nitrification instead of ammonification as a measure to determine the relative availability of various nitrogenous fertilizers (15, 2). Besides, ammonia and organic compounds derived from proteins are only transition products and do not accumulate in the soil to any appreciable extent and therefore cannot safely be used as a measure.   On the other hand, the determination of nitrates gives more satisfactory return, for it is an end product and, as such, tends to accumulate in the soil, hence valuable information has been secured by the systematic study of nitrate formation and its

relation to crop growth.   The nitrifiability of a given form of nitrogen appears to be the most reliable laboratory criterion to judge its availability.

As the simpler decomposition products of proteins are very numerous and of widely varying compositions and properties, it becomes obvious that the processes of their nitrification may be rapid or slow depending upon the composition of the compounds and the manner in which the nitrogen atoms are bound in them.   It, therefore, became essential to make a study of the nitrification of the pure nitrogenous organic compounds derived from the decomposition of proteins, because the questions naturally arise: Is the comparative rate of nitrifiability of the nitrogen of the amino acids belonging to the same series the same?   Is there any difference between the rate of nitrification of the amino acids of one series and that of another?   Is the nitrogen of an organic compound having only a chain formula more easily converted into nitric acid than such nitrogen as is contained in the ring of the heterocyclic compounds?

Since no work has yet been done on the nitrifiability of nitrogenous organic compounds derived from the decomposition of proteins, the following experiments were undertaken with the object of obtaining some information on the above points, which may eventually throw some light on the question of the availability of these compounds and consequently of the availability of the nitrogen in different organic fertilizers.   The present paper deals mainly with the results of the nitrification of mono-amino-mono-carboxylic acids and tryptophan.   Experiments with the remaining amino acids and other nitrogenous compounds found in the soil, are in progress.

EXPERIMENTAL

The soil used in this work was taken from a plot of the estate of the Agricultural College, Cawnpore.   The field in question had been utilized as garden land for more than 25 years.   It was only 2 years before the sample was taken that it was converted into arable land.   The sample was taken about two months after the harvest of the *Rabi* crop and just before the beginning of the rains.

A very large sample of the surface soil was secured so that the whole of the work could be done on the same soil.   It was air-dried in shade, sieved, thoroughly mixed and stored in large earthenware glazed pots and covered for future use after determining by the Kjeldahl-Gunning method the total nitrogen, which amounted to 0.0847 per cent.

The soil was a light loam with a pH value 6.35 as determined by the calorimetric method following the work of Clark and Lub (4).   Its chemical and physical compositions are given in tables 1 and 2.

The method adopted was the ordinary tumbler method but as the glass of the ordinary tumbler is likely to be corroded when kept for some time in contact with the soil containing moisture and acids, glazed earthenware pickle jars with lids of the same material and having a capacity of about 800 cc. and a diameter about 3.5 inches were used.

To 100-gm. portions of the air-dried soil, weighed into sterile pickle jars, were added solutions of different amino acids neutralized with an alkaline solution and containing 15 mgm. of nitrogen. This together with 0.5 gm. of pure calcium carbonate and sufficient sterile distilled water adjusted to the optimum moisture content, was well mixed with the soil in the jars, which after the weight of each jar had been taken were then covered and incubated for 30 and 40 days, at the room temperatures. The moisture content was kept up

TABLE 1

Mechanical analysis of soil

	per cent
Moisture	0.98
Loss on ignition	3.92
Coarse sand	1.43
Fine sand	54.97
Silt	15.28
Fine silt	13.00
Clay	10.08
Calcium carbonate	0.08
	99.74

TABLE 2

Chemical analysis of soil

	per cent
Moisture	0.98
Loss on ignition*	3.92
Insoluble silica	82.60
Fe_2O_3 and Al_2O_3	10.01
P_2O_5	0.75
CaO	0.56
MgO	0.54
SO_3	0.04
K_2O	0.23
Na_2O	0.34
	100.00

* Containing: N, 0.08 per cent; CO_2, 0.05 per cent.

during the incubation period by adding water to weight every week. Two more jars for each period in addition to those containing amino acids were incubated. To one was added a solution of ammonium sulfate calculated to contain the same quantity of nitrogen as in the solutions of amino acids. The other was a control jar containing only the soil, 0.5 gm. $CaCO_3$, and the optimum quantity of sterile distilled water. Calcium carbonate was added to each jar to prevent the soil from becoming acidic during nitrification and thus to keep the field clear for bacterial action.

At the end of each incubation period nitric nitrogen was determined in each jar. The soil of each jar was transferred to a Büchner filter and leached with distilled water till the washings were free from nitrates, as shown by the diphenylamine test. The filtrate was collected, evaporated on a water bath to a small bulk and the nitrate determined by the modified Schloesing method (1).

The maximum capacity for water of this soil was determined three times according to Hilgard's method (6). The average came to 49.4 per cent. Hutchinson and Milligan (8) have found out that $\frac{3}{5}$ saturation is the optimum moisture for nitrification in Pusa soil. Therefore $\frac{3}{5} \times 49.4 = 18.5$ per cent was kept as the optimum moisture for the soil in hand.

The amino acids used in these experiments were:

1. Phenylalanine   4. Tyrosine
2. Leucine   5. Cystine
3. Tryptophan   6. αAlanine

TABLE 3

Results of nitrogen determinations

AMINO ACIDS	NITROGEN BY FORMULA	NITROGEN BY KJELDAHL'S METHOD
	per cent	*per cent*
1. Phenylalanine...................................	8.48	8.30
2. Leucine..	10.69	10.61
3. Tryptophan....................................	13.72	12.95
4. Tyrosine......................................	7.73	7.57
5. Cystine.......................................	11.67	11.46
6. α Alanine.....................................	15.73	15.64
7. Ammonium sulfate.............................	21.21	20.75

To determine the purity of the above amino acids as well as of ammonium sulfate, their total nitrogen was determined by Kjeldahl's method. The quantities of nitrogen found together with that calculated from their formulas are given in table 3. All the calculations in the experiments are based upon the actual quantities of nitrogen found and not on the theoretical ones.

The first two amino acids were procured from Messrs. Baird and Tatlock (London) Limited, 14–15 Cross Street, Hatton Garden, London, England, and the rest from the Special Chemical Company Limited, Illinois, U. S. A.

The investigation was carried out in two series: In the first one phenylalanine, leucine, and ammonium sulfate were used, and in the second tyrosine, tryptophan, α alanine, cystine and ammonium sulfate. The results are given in tables 4 and 5. The nitric nitrogen of the control jar was subtracted in all cases and the calculations of the percentages of nitrogen nitrified were made on the absolute amount of nitrate produced.

After laying the plan for the experiment, the author had to wait several months to start the work because of the late arrival of amino acids from dif-

H. N. BATHAM

ferent countries. Meanwhile, in order to study the fluctuations which the
nitric nitrogen content of the soil undergoes under experimental conditions
during different periods of the year, blank experiments were started similar
to the control jars described above.

The seasons of the agricultural year in Upper India rapidly change from
one to another resulting in a wide variation in their characters. For the
benefit of those unfamiliar with Indian conditions, it will not be out of place
to give here a short account of the different seasons prevalent in the United
Provinces.

TABLE 4

INCUBATION PERIOD	CONTROL	PHENYLALANINE			LEUCINE			AMMONIUM SULFATE		
	Nitric nitrogen found at the end of incubation period	Nitric nitrogen found	Increase over the control	Nitrogen nitrified found	Nitric nitrogen found	Increase over the control	Nitrogen nitrified found	Nitric nitrogen found	Increase over the control	Nitrogen nitrified found
	mgm.	mgm.	mgm.	per cent	mgm.	mgm.	per cent	mgm.	mgm.	per cent
Nitrification of amino acids in 30 days										
12/ 4/23–1/ 4/24	3.11	9.75	6.64	44.26	9.95	6.84	45.58	12.67	9.56	63.48
12/20/23–1/19/24	3.39	9.33	5.94	39.60	10.05	6.66	44.38	13.26	9.87	65.54
1/24/24–2/24/24	4.03	11.13	7.10	47.33	10.62	6.59	43.92	14.49	10.46	69.45
3/14/24–4/13/24	3.92	11.28	7.36	49.06	9.28	5.36	35.72	16.48	12.56	83.40
Nitrification of amino acids in 40 days										
12/ 4/23–1/13/24	3.76	12.83	9.07	60.46	12.09	8.33	55.51	12.68	8.92	59.23
12/20/23–1/29/24	4.17	10.71	6.54	43.60	9.20	5.03	33.52	14.88	10.71	71.11
1/24/24–3/ 5/24	3.96	10.55	6.59	43.93	10.72	6.76	45.05	14.53	10.59	70.32
3/14/24–4/23/24	4.79	12.06	7.27	48.46	13.01	8.22	54.78	16.77	11.98	79.55

The rainy season begins in July or the end of June and lasts until the middle
of October. The cold weather commences in November and ends in March,
when the hot and dry season sets in and continues to the last days of June.
The above changes of seasons give rise to two principal crops. The summer
or *Kharif* crop begins and ends with the rainy weather and the autumn or
Rabi crop with the cold one.

The changes in the nitric nitrogen content of the soil have a direct bearing
on the crop growth. The figures, obtained from August, 1923 to July, 1924,
under laboratory conditions and with optimum moisture content, may throw
some light on the point. They are given in table 6 and are also shown graphi-
cally in figure 1 together with the air temperature of the laboratory.

TABLE 5

INCUBATION PERIOD	CONTROL	CYSTINE			TRYPTOPHAN			ALANINE			TYROSINE			AMMONIUM SULFATE		
	Nitric nitrogen found at the end of incubation period, mgm.	Nitric nitrogen found, mgm.	Increase over the control, mgm.	Nitrogen nitrified found, per cent	Nitric nitrogen found, mgm.	Increase over the control, mgm.	Nitrogen nitrified found, per cent	Nitric nitrogen found, mgm.	Increase over the control, mgm.	Nitrogen nitrified found, per cent	Nitric nitrogen found, mgm.	Increase over the control, mgm.	Nitrogen nitrified found, per cent	Nitric nitrogen found, mgm.	Increase over the control, mgm.	Nitrogen nitrified found, per cent
Nitrification of amino acids in 30 days																
3/27/24–4/26/24	4.70	10.23	5.53	36.86	12.62	7.92	52.79	11.58	6.88	45.84	13.12	8.42	56.11	15.01	10.31	68.46
4/24/24–5/23/24	5.33	10.93	5.60	37.32	13.29	7.96	53.06	12.54	7.21	48.04	12.89	7.56	50.33	15.58	10.25	68.06
5/14/24–6/13/24	4.93	11.40	6.47	43.12	13.89	8.96	59.72	11.11	6.18	41.18	9.40	4.47	29.79	16.25	11.32	75.17
6/10/24–7/10/24	6.26	12.76	6.50	43.32	14.42	8.16	54.39	13.52	7.26	48.38	9.64	3.38	22.52	15.79	9.53	63.28
Nitrification of amino acids in 40 days																
3/27/24–5/6/24	5.37	9.99	4.62	30.79	12.53	7.16	47.73	12.54	7.17	47.78	11.57	6.20	41.32	13.76	8.39	55.71
4/24/24–6/2/24	6.39	11.86	5.47	36.46	13.26	6.87	45.79	11.58	5.19	34.58	10.77	4.38	29.19	15.52	9.13	60.62
5/14/24–6/23/24	7.56	13.89	6.33	42.19	15.13	7.57	50.46	15.49	7.93	52.84	11.91	5.67	37.79	15.32	9.08	60.29
6/10/24–7/20/24	7.52	12.57	5.05	33.66	.....	.....	.....	.....	.....	.....	11.19	3.95	26.32	17.44	9.92	65.88

DISCUSSION OF RESULTS

In comparing the figures given in tables 4 and 5, it should be remembered that the nitric nitrogen was determined after 30 and 40 days. It is true that a few days more or less would not only have increased or decreased the amount of nitrates produced but would also have modified to some extent the relative availability of the different amino acids. The results obtained, however, are of considerable interest. From the data given it appears that none of the amino acids can compete with ammonium sulfate in nitrifiability. In the case of the ammonium salt, the quantity of nitrogen nitrified is always above 50 per cent, sometimes reaching 80 per cent but generally remaining between 60 and 70 per cent. As regards the amino acids, the general trend of the nitrification of their nitrogen excepting that of cystine and tryptophan, has been between 40 and 50 per cent. It is only very rarely that the nitri-

TABLE 6

Fluctuations of the nitric nitrogen content of the soil during the year

DATE	NITRIC NITROGEN IN 100 GM. AIR-DRIED SOIL— 30 DAYS INCUBATION PERIOD	DATE	NITRIC NITROGEN IN 100 GM. AIR-DRIED SOIL— 40 DAYS INCUBATION PERIOD
	mgm.		*mgm.*
8/13/23	3.14	8/23/23	4.29
9/13/23	3.12	9/22/23	4.11
11/12/23	3.37	11/22/23	4.89
1/ 4/24	3.11	1/13/24	3.76
1/19/24	3.39	1/29/24	4.17
2/24/24	4.03	3/ 5/24	3.96
3/ 9/24	4.23	3/19/24	3.29
4/13/24	3.92	4/23/24	4.79
4/26/24	4.70	5/ 6/24	5.37
5/23/24	5.33	6/ 2/24	6.39
6/13/24	4.93	6/23/24	7.56
7/10/24	6.26	7/20/24	7.52

fication of the nitrogen of some of these acids has gone above 50 per cent or below 30 per cent.

Turning now to cystine it is found that it has given figures below 40 per cent in the majority of the experiments and never above 43.32 per cent. This depressed production of nitrates which is more marked in the incubation period of 40 days, may be due to the presence of sulfur in the compound, which may be producing substances capable of retarding nitrification.

Tryptophan contains two atoms of nitrogen, one in the ring and the other in the chain thus:

$$C_6H_4 \begin{array}{c} C \\ \diagdown \\ NH \end{array} CH \quad \rightarrow CH_2 \cdot CH(NH_2) \cdot COOH$$
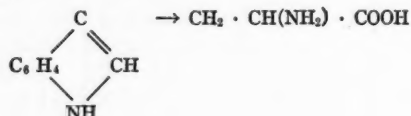
Fig. 1. Nitrate Accumulation, Cawnpore, August, 1923, to July, 1924

It has given results above 50 per cent in the majority of the determinations and never below 45 per cent. Thus the figures obtained for tryptophan are somewhat higher than those obtained for other acids, indicating thereby that the compound containing both ring nitrogen and chain nitrogen has better nitrification value than compounds having only chain nitrogen, but it cannot be alleged at this stage of the experiment that out of the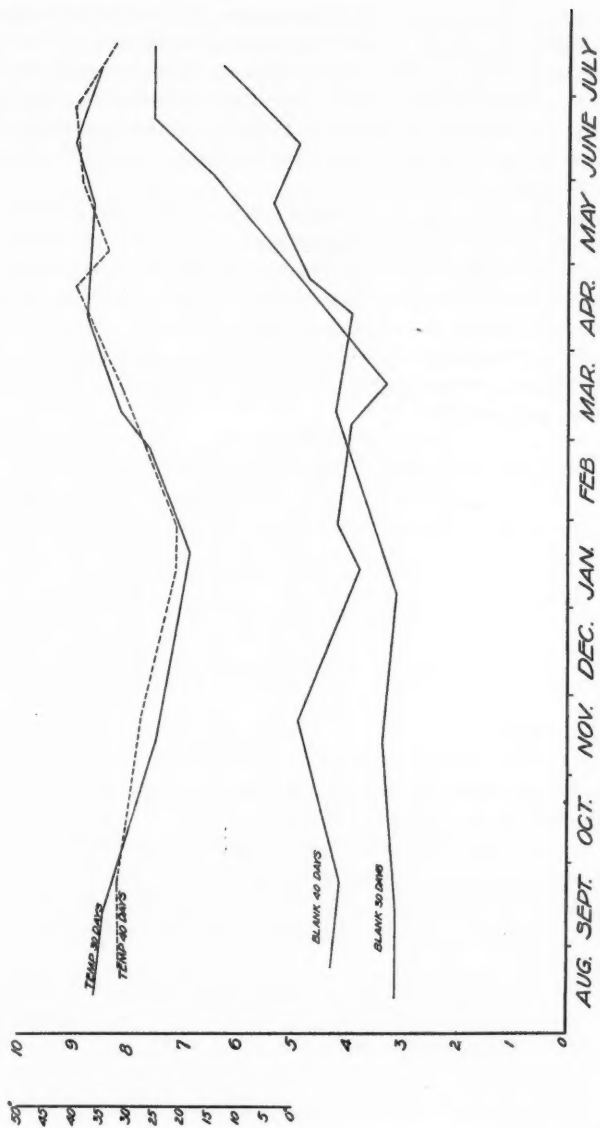 two atoms of nitrogen one is more easily nitrified than the other, unless and until some other similar compounds are tried.

The case of tryosine is also remarkable. The figures obtained have varied from 56 to 22 per cent. This variation appears to be brought about by the changes in temperature and the putrefactive nature of the substance. The most favorable temperature for putrefaction is between 37° and 45°C. As the temperature during the experiment approached 40°C., the quantity of nitrogen nitrified decreased accordingly, probably because of the formation of phenol, which is a strong antiseptic, and the escape of nitrogen as ammonia during putrefaction.

TABLE 7

Average results of nitrification of amino acids and their nitrogen-carbon ratio

AMINO ACID	NITRIFIED AVERAGE	N–C RATIO
	per cent	
1. Tryptophan...................................	51.49	1:4.7
2. Phenylalanine.................................	47.08	1:7.7
3. α alanine......................................	45.46	1:2.5
4. Leucine.......................................	44.80	1:5.1
5. Tyrosine......................................	39.70	1:7.7
6. Cystine.......................................	37.96	1:2.6
7. Ammonium sulfate.............................	67.46	

From the study of the different figures secured for each acid there seems to be no difference in the relative availability of most of them; sometimes the nitrogen of one is more effectively nitrified and sometimes that of the other. If the average of the four figures obtained for each acid is tabulated, the comparative availability of various amino acids as shown by nitrification may become more evident. The average results and the nitrogen-carbon ratio are given in table 7.

Thus from table 7 a graded list of various amino acids can be prepared on the basis of their relative availability which is represented diagrammatically in figure 2, the availability of ammonium sulfate being taken as 100; but the differences among most of them during the same incubation period or at the various periods are so great that they can almost be considered within the experimental error.

Among the amino acids used in these experiments five (phenylalanine, leucine, cystine, α alanine, and tyrosine) belong to the mono-amino-monocarboxylic acid series, and the remaining tryptophan, to the series of hetero-

cyclic compounds and has given the highest results. When the acids of the mono-amino-mono-carboxylic series are taken into consideration it appears that all of them are nitrified at practically the same rate, although the slight depression in the accumulation of nitrates in the jars containing tyrosine and cystine was noted and explained in the preceding paragraphs.

Lipman, Brown, and Owen (15) while determining the relative availability of different nitrogenous organic fertilizers as measured by nitrification have shown that the substances with the narrower carbon-nitrogen ratio are nitrified not only more rapidly but also more thoroughly. The figures given in table 7 show that although phenylalanine has the widest carbon-nitrogen ratio, still its nitrification value is not in any way inferior to the nitrification values of leucine, α alanine and tryptophan which have narrower carbon-
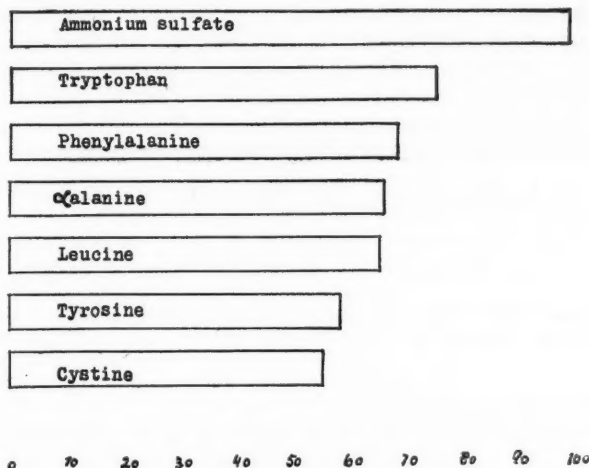
FIG. 2. RELATIVE AVAILABILITY OF AMINO ACIDS

nitrogen ratios. Tyrosine is another compound having the widest nitrogen-carbon ratio and according to table 7 seems apparently to conform to the conclusion of the above investigators, but according to table 5 its nitrification value appears to remain superior to those of leucine and α alanine as long as the temperature does not become most favorable for putrefaction. Besides, the compound cystine has the narrowest carbon-nitrogen ratio and has also yielded the least quantity of nitric acid. It is quite possible that the nitrogen-carbon ratio may be playing an important part in the nitrification of heterogeneous complex organic nitrogenous substances, but the nitrification of pure nitrogenous organic compounds appears to be independent of the carbon-nitrogen ratio. Therefore, the greater availability of a material of a narrower ratio over those of a wider ratio cannot be considered applicable to pure nitrogenous organic compounds.

FIG. 3. NITRATE ACCUMULATION, PUSA, APRIL TO SEPTEMBER, 1910

FIG. 4. NITRATE ACCUMULATION, CAWNPORE, SEPTEMBER, 1919, TO APRIL, 1920

From table 6 it is found that during the incubation period of 30 days the nitric-nitrogen content of the soil is at its minimum in the months of August and September; after that there is a rise, followed by a fall in the month of January. The greatest quantity of nitric nitrogen occurs during the months of June and July. The rise and fall of the incubation period of 40 days agree in most instances with those of 30 days. The fig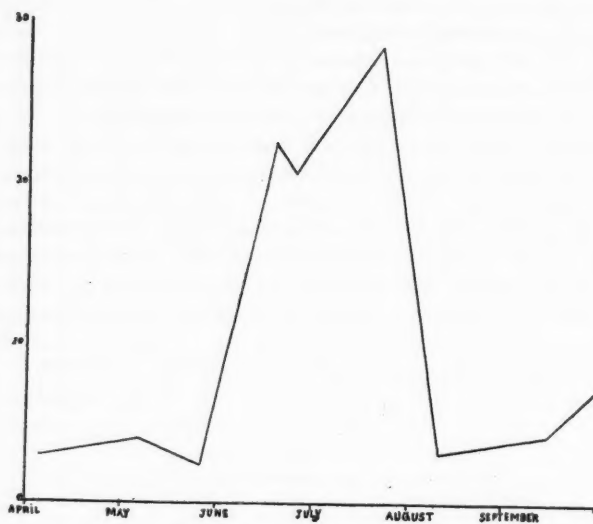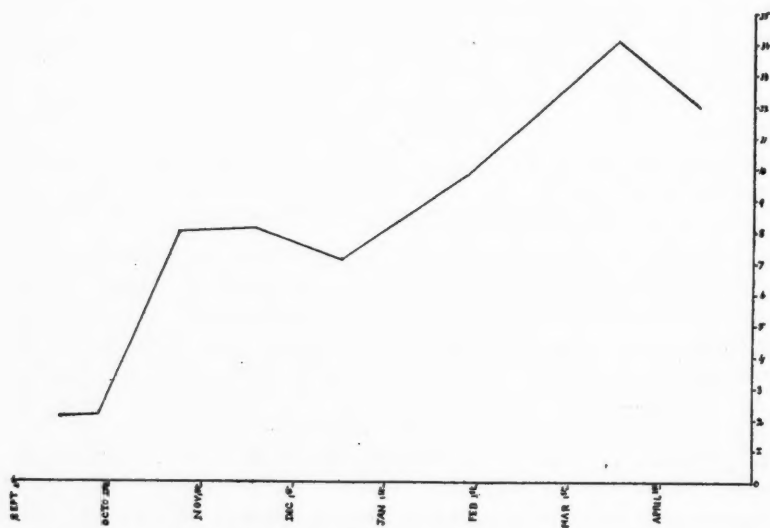ures obtained for the former periods are always higher than those for the latter except in the month of March when they have become very low.

Determinations of nitrogen in soils at different times of the year were also carried out by Leather (13) and Sen (22) at Pusa, and Clarke (3) at Cawnpore. The experiments by Leather and Clarke were carried out in soils *in situ* and those by Sen under artificial conditions and with a special purpose. Although the conditions under which the above experiments were performed were quite different from those of the author, still there is a striking similarity between the results of other workers and those of the author which can be seen from the curves given in figures 1, 3, and 4. They add considerable support to the author's observations from which it can be concluded that the amount of nitric nitrogen in the soil fluctuates regularly and that the rise and fall of the activity of the nitrifying bacteria take place at definite periods of the year.

Gowda of the Iowa Agricultural Experiment Station (5) has also very recently determined the effect of seasonal conditions on the nitrate content and the nitrifying power of an Iowa soil. He says in his paper:

There was a large accumulation of nitrates in June with a gradual decrease in July, and a rapid decrease in August and September when it reached the minimum. In October there was a slight increase in nitrates.

Thus his findings confirm the author's results and at the same time show that the fluctuations of nitrate content of the Indian soils at definite times of the year are similar to those of the Iowa soil.

From the amounts of nitric nitrogen found in control jars it can be observed that the nitrifying bacteria remained active in the soil even when kept in stock for more than a year.

SUMMARY

The results of these experiments on this particular soil type lead to the following conclusions:

1. In this soil ammonium sulfate is more effectively nitrified than any of the amino acids.
2. The nitrogen of the compound tryptophan containing both ring nitrogen and chain nitrogen is more readily nitrifiable than that of the compounds containing only chain nitrogen.
3. The average of the results showed that the amino acids, belonging to the mono-amino-mono-carboxylic acid series are nitrified at about the same rate.
4. Tyrosine and cystine are less available than phenylalanine, leucine, α alanine, and tryptophan.
5. The presence of sulfur in cystine appeared to depress the nitrification of its nitrogen.

6. The nitrification of amino acids appears to be independent of the nitrogen-carbon ratio.

7. The amount of nitric nitrogen in the soil fluctuates regularly and the rise and fall of the activity of the nitrifying bacteria takes place at definite periods of the year.

8. The nitrifying bacteria remained active in the soil even when kept in stock for more than a year.

REFERENCES

(1) ADDYMAN, F. J. 1904 Agricultural Analysis. Longmans, Green & Co., New York

(2) ALLISON, F. E. 1910 Some availability studies with ammonium phosphate, and its chemical and biological effects upon the soil. *In* Soil Sci., v. 5, p. 1–79.

(3) CLARKE, G. 1922 Nitrate fluctuation in the Gangetic alluvium and some aspects of the nitrogen problem in India. *In* Agr. Jour. India, v. 18, no. 5, p. 463–475.

(4) CLARKE, W. M. 1915 The Determination of Hydrogen Ions. The Williams & Wilkins Co., Baltimore.

(5) GOWDA, R. N. 1924 Nitrates and nitrification in field soils. *In* Soil Sci., v. 17, p. 333–342.

(6) HALL, A. D. 1908 Soil. E. P. Dutton & Co., New York.

(7) HUTCHINSON, H. B., AND MILLER, N. H. J. 1911 Direct assimilation of organic and inorganic forms of nitrogen by higher plants. *In* Centbl. Bakt. (etc.), Abt. 2, Bul. 30, p. 513.

(8) HUTCHINSON, C. M., AND MILLIGAN, S. 1914 Green manuring experiment 1912–1913. Agr. Res. Inst. Pusa Bul. 40.

(9) JODIDI, S. L. 1911 Chemical nature of the organic nitrogen in the soil. Iowa Sta. Res. Buls. 1 and 3.

(10) KELLEY, W. P., AND THOMPSON, R. A. 1914 The organic nitrogen of Hawaiian soils. *In* Jour. Amer. Chem. Soc., v. 36, p. 429–444.

(11) LATHROP, E. C., AND BROWN, B. E. 1911 Studies in organic soil nitrogen. *In* Jour. Indus. Engin. Chem., v. 3, p. 657.

(12) LATHROP, E. C. 1912 Guanine from a heated soil. *In* Jour. Amer. Chem. Soc. v. 34, p. 1260.

(13) LEATHER, J. W. 1911 Records of drainage in India. In Dept. Agr. India. Chem. Ser., v. 2, no. 2, p. 63–140.

(14) LIPMAN, J. G., AND BLAIR, A. W. 1918 Twenty years' work on the availability of nitrogen in nitrate of soda, ammonium sulfate, dried blood and farm manure. *In* Soil Sci., v. 5, p. 291–300.

(15) LIPMAN, J. G., BROWN, P. E. AND OWEN, I. L. 1910 Relative availability of nitrogenous materials as measured by nitrification. *In* N. J. Agr. Exp. Sta. 31st Ann. Rpt., p. 152–155.

(16) PLIMMER, R. H. A. 1908 The Chemical Constitution of the Proteins. Part I: Analysis. Longmans, Green & Co., New York.

(17) ROBINSON, C. S. 1911 Organic nitrogenous compounds in peat soils: II. Mich. Agr. Exp. Sta. Tech. Bul. 7.

(18) RUSSELL, E. J., AND HUTCHINSON, H. B. 1909 The effects of partial sterilization of soil on the production of plant-food. *In* Jour. Agr. Sci., v. 3, p. 111–144.

(19) SCHREINER, O., AND SHOREY, E. O. 1910 Chemical nature of soil organic matter. *In* U. S. Dept. Agr. Bur. Soils Bul. 74.

(20) SCHREINER, O., REID, H. S., AND SKINNER, J. J.   1907   Certain organic constituents of soils in relation to soil fertility.   *In* U. S. Dept. Agr. Bur. Soils Bul. 47.

(21) SCHREINER, O., AND SKINNER, J. J.   1912   Nitrogenous soil constituents and their bearing on soil fertility.   *In* U. S. Dept. Agr. Bur. Soils Bul. 87.

(22) SEN, J. N.   1918   Influence of potsherds on nitrification in the Indian alluvium.   *In* Jour. Agr. Sci., v. 9, p. 32.

(23) SHOREY, E. C.   1906   Report on agricultural investigations in Hawaii.   *In* U.S. Dept. Agr. Office Exp. Sta. Bul. 170, p. 25–38.

(24) SHOREY, E. C.   1906   Organic nitrogen in Hawaiian soils.   *In* Hawaii Agr. Exp. Sta. Ann. Rpt. 1906, p. 37–59.

(25) SHOREY, E. C.   1913   Some organic soil constituents.   *In* U. S. Dept. Agr. Bur. Soils Bul. 88.

(26) WALTERS, E. H.   1915   The presence of proteoses and peptones in soils.   *In* Jour. Indus. Engin. Chem., v. 7, no. 10, p. 860.
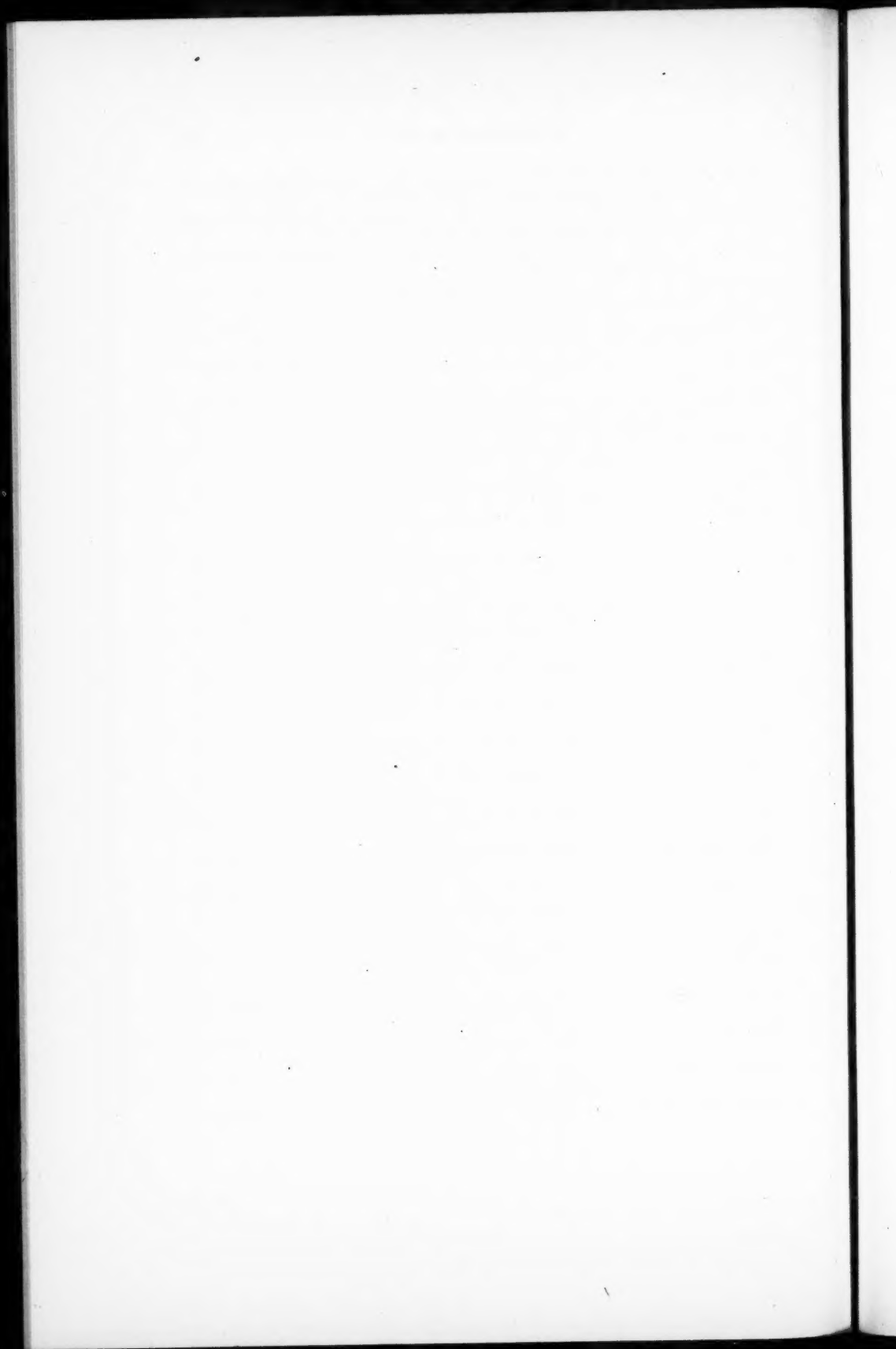
REVIEW OF GERMAN LITERATURE ON PLANT NUTRITION AND SOIL SCIENCE, FOR 1924[1]

PLANT PHYSIOLOGY

Nitrogen as a growth factor

HASELHOFF, E., AND HAUN, F. 1924. *Studies on the nitrogen and ammonia contents of the soil. In* Die Landwirtschaftlichen Versuchs-Stationen, v. 52, p. 90–103.

The authors determine the total nitrogen content of the soil by the Kjeldahl Jodlbaur method, the ammonia colorimetrically with Nessler's reagent, and the nitrates with diphenylamin-sulfuric acid. The largest percentages of ammonia and nitrates were found in the surface layers, both on cropped soil and on bare soil. The average ammonia content of cropped soil, however, is much lower than of uncropped soil. The nitrate nitrogen apparently increases from fall until summer, but a decrease was noticed from summer until harvest time. Conclusive data on the effect of fallowing, manuring, and green manuring, and on the effect of various crops on the nitrogen content of the soil were not obtained.

HASELHOFF, E. 1924. *Experiments on the nitrogen exploitation in the soil. In* Landwirtschaftlichen Versuchs-Stationen, v. 52, p. 73–89.

The author concludes from his field experiments that only in the first year is an increase in the nitrogen content of the soil obtained by fallowing. The next year the nitrogen content will again be reduced to the original amount or less. The nitrogen of a soil to which organic fertilizers have been applied is taken up by the plants in a more advantageous way if the land is not fallowed.

HASELHOFF, E., AND LIEHR, O. 1924. *Studies on the effect of organic fertilizers on the biochemical composition of the soil. In* Landwirtschaftlichen Versuchs-Stationen, v. 52, p. 43–59.

For a number of years field experiments on parcels varying from 1 to 100 square meters in area have been carried on. The potassium and phosphoric acid treatments being the same in all cases, the nitrogen was applied as sulfate of ammonia, as stable manure, and as green manure, the latter from either a serradella, pea, or clover crop. The number of bacteria for each gram of

soil was determined three times a year, but no positive results were obtained. The transformation of organic nitrogen compounds (hornmeal and guanol) into ammonia and nitrates by soil organisms was determined by J. Vogel's method.   Apparently an increase in the nitrifying power of the soil took place until fall, followed by a decrease lasting until spring.   No conclusive data were obtained from experiments on nitrogen fixation.

LITTAUER, FRANZ. *Decomposition of urea in the soil. In* Zeitschrift für Pflanzenernährung and Düngung, pt. A, p. 165–179.

The decomposition of urea in the soil depends on the soil type, soil moisture, and soil temperature.   The temperature being the same, the decomposition proceeds faster in a loam soil than in a sandy soil.   The decomposition is checked by drought but increases with increasing temperature and moisture content of the soil, as long as the latter does not exceed the average water capacity.

Phosphoric acid as a growth factor

LEMMERMANN, O., AND WIESSMANN, H.   *Studies on the phosphorus requirements of the German arable soils. In* Zeitschrift für Pflanzenernährung und Düngung, pt. B, p. 273–282.

Field experiments carried on all over Germany led to the following conclusions: In 1922, of 68 soils examined for phosphoric acid, 16, or 23.5 per cent gave a distinct reaction; 10, or 14.7 per cent gave a weak reaction; and 41, or 61.7 per cent gave a doubtful or no reaction on phosphoric acid.   During 1923, 64 soils were examined with the result that 15, or 23.4 per cent responded distinctly; 4, or 6.3 per cent reacted weakly; 9, or 14.1 per cent reacted doubtfully; and 36, or 56.2 per cent did not respond at all to an application of a phosphorus fertilizer.

BRÜNE, F., AND TACKE, B.   *The phosphorus requirement of lupines on heather sand soil. In* Zeitschrift für Pflanzenernährung und Düngung, pt. B, p. 41–46.

The authors prove that Aereboe's theory on the saving of phosphoric acid by fertilizing legumes with potassium and nitrogen fertilizers does not hold true for lupines on heather sand soil.   Neither a potassium nor a potassium-nitrogen application enabled the lupines to take up a sufficient amount of phosphoric acid from the soil.

LEMMERMANN, O., AND WIESSMANN, H.   *Further investigations on the yield-increasing effect of silicic acid in the absence of sufficient quantities of phosphoric acid. In* Zeitschrift für Pflanzenernährung und Düngung, pt. B, p. 185–197.

The yield-increasing effect of silicic acid is once more corroborated by large series of pot experiments.

DENSCH AND HUNNIUS. 1924. *The influence of the soil-water content on the yield, on the grain-straw ratio, and on the phosphorus nutrition of oats at various times in the growth period. In* Landwirtschaftlichen Versuchs-Stationen, v. 53, no. 1–2, p. 91–102.

Summary: 1. A long period of drought caused an essential decrease in the straw yield but did not affect the growth of the flowering parts of the plant until the early part of July when the drought also showed its bad effect on the grain formation.

2. A decrease in the soil-water content during the early part of the developing period of the panicles resulted in a decreased straw yield as well as in a decreased grain yield.

3. The effect of changing the soil-water content at various times in the growth period was also noticeable when large applications of phosphoric acid were made.

4. The phosphoric acid is taken up by the oats until the panicles appear and under favorable moisture conditions the whole amount is available for the grain formation.

5. Similar results were obtained in the case of potassium. Even if the period of drought ends during the stretching period, the plant is able until the panicle formation to take up as much potassium as when under continual favorable moisture conditions.

6. A sufficient quantity of nitrogen, however, could not be taken up, even when the lack of moisture ended during the stretching period, which was as early as June 21. If moisture conditions were kept favorable until the panicle formation, the plants were still not able to get their full nitrogen requirement. This shows that under favorable moisture conditions oats take up nitrogen even after the panicle formation, and the nitrogen nutrition lasts until near their ripening.

Potassium as a growth factor

ESCHENHAGEN, M. 1924. *On the potassium nutrition of young rye plants, grown in an unusually small volume of soil.* Thesis, Königsberg, Botanisches Archiv, v. 7, p. 418–448.

The author applies Neubauer's method for the study of the nutrient contents of the soil, but he uses pure sand as a growth medium, applying varying amounts of potassium fertilizer. Considering growth periods of varying duration (up to 50 days), varying soil moisture conditions, and varying applications of potassium, he finds that with increasing amounts of potassium the dry weight of the plants follows the action law of the growth factors. The amount of potassium absorbed by the plants, however, depends not only on the amount of potassium available in the soil but also on all other growth factors. It is pointed out that the absorption of potassium is controlled by the concentration of the potassium solution in the soil and does not depend on the lack of available potassium. This shows that Neubauer's method can be used only within certain limits.

Lime as a soil factor

ARRHENIUS, O. *The lime requirements of the soil considered from a plant physiological standpoint. In* Zeitschrift für Pflanzenernährung und Düngung, pt. A, v. 3, p. 129–151.

The author reviews all methods for the determination of the lime requirements of the soil and discusses more particularly the colorimetrical and electro-

metrical methods for determination of the hydrogen-ion concentration. An extensive bibliography is included.

LEMMERNAMM, O., AND FRESENIUS, L. *Investigations on the behavior of lime in the soil.* *In* Zeitschrift für Pflanzenernährung und Düngung, pt. A, v. 3, p. 1–20.

Lime applied in the form of quicklime combines with the soil very quickly. The combination takes place with or without a simultaneous base exchange; in the former case it is followed by an extensive adsorption of the various hydroxides formed. Base exchange takes place when $CaCl_2$ and $Ca (HCO_3)_2$ are applied to the soil. The adsorption by the soil of $Ca (OH)_2$ is not quite checked by carbon dioxide. The combination of various soils with varying amounts of calcium hydroxide accelerates the decomposition of organic substances. Small amounts of lime such as those which are absorbed very quickly by the soil, will suffice for this purpose.

RAMANN, E. *The chemico-physical actions of quicklime and lime stone on mineral soils.* *In* Zeitschrift für Pflanzenernährung und Düngung, pt. A, v. 3, p. 257–273. *Also in* Soil Sci., v. 18, p. 387–400.

The author discusses briefly his studies on "Adsorption by quartz," "Base exchange," "Acids and acid-reacting salt solutions," "Buffer actions," "Saturation grades of soils," "Absorptivity of exchange bases for plants," "Quicklime and marl fertilizing," and "The effect of fertilizers in relation to the size of the particles." It is stated that the efficiency of very insoluble fertilizers depends, on one hand, on the surface area (velocity of saturation of the solution) and on the other hand on the free distance between the particles (length of the path of diffusion).

BLANCK, E., AND LOHMANN, W. *On the transformation of quicklime into carbonated lime in the soil.* *In* Zeitschrift für Pflanzenernährung und Düngung, pt. A, v. 3, p. 91–110.

The following conclusions were reached:

1. Quicklime applied to loam soil or sandy soil is transformed quantitatively into calcium carbonate; completion of this transformation takes a relatively long time.

2. The rapidity of transformation depends in the first place on the moisture conditions of the soil.

3. A double application is transformed in about the same time as a single lime dressing; the velocity of transformation, therefore, does not seem to depend on the amount of quicklime applied. Repeated mixing of the limed soil accelerates the transformation.

Soil reaction

KÖNIG, J., HASENBÄUMER, J., AND KRÜGER, E. 1924. *Relations between the plant-food constituents of the soil and their absorption by oats. Influence of crops and fertilizers on the soil acids.* *In* Landwirtschaftliche Jahrbücher, v. 58, p. 87–134.

The authors determined the available plant nutritives of the soil by steam treatment and by extraction with 1 per cent citric acid. The values obtained are compared with the analytical values of the oats grown on this soil. Correlating figures were not obtained except in the case where potassium was determined by steam treatment. It was found that physiological acid fertilizers increased the acid content of the soil whereas the soil acids were decreased or even neutralized by marling. The influence of variously fertilized oat cultures on the hydrogen-ion concentration of the soil was studied in pot and field experiments. The oats either did not change the soil acidity or increased it only slightly. Studies on the influence of various unfertilized plants on the hydrogen-ion concentration of the soil showed that the soil acidity was increased most by peas, lupines, and buckwheat. The juice pressed from the roots of these plants showed a higher acidity than that from plants which increased the soil acidity less or not at all.

LEMMERMANN, O., AND FRESENIUS, L. *On the reaction of German soils and its significance.* *In* Zeitschrift für Pflanzenernährung und Düngung, pt. B, v. 3, p. 233–247.

The characters and causes of the various forms of acidity are discussed and it is concluded that a problem of acid soils has not yet arrived in Germany. The soil reaction, however, should be under control continuously and the danger of formation of alkali soils should be kept in mind.

DENSCH, HUNNIUS, AND PFAFF. *A contribution to the soil acidity problem.* *In* Zeitschrift für Pflanzenernährung und Düngung, pt. B, v. 3, p. 248–261.

The authors are opposed to the frequent habit of attributing all physiological injuries of plants to soil acidity. These injuries can usually be accounted for by unfavorable changes in soil structure due to lack of lime, which causes insufficient aeration and thus affects plant growth and the development of microörganisms in the soil.

SCHUCKENBERG, AUGUST. *Plant injuries on acid soils.* *In* Zeitschrift für Pflanzenernährung und Düngung, pt. A, v. 3, p. 65–90.

The influence on plants of the forms and grades of acidity as formulated by Kappen was studied in cultures on acid soils and in germination tests on acid mineral soils. A study was also made on the influence of humic acids on germination in the four different forms of acidity. The causes of the detrimental actions of the various forms of acidity on the plants are discussed.

ARND, TH. *Determination and character of the acidity of peat soils.* *In* Zeitschrift für Pflanzenernährung und Düngung, pt. A, v. 3, p. 227–256.

The author claims to be able, by means of the bacteriological method advocated by the Peat Soils Experiment Station, to determine the hydrogen-ion

concentration produced by the total acids and acid salts. The assumption of an acidity exchange is doubtful, and the occurrence of a hydrolytical acidity has not been proved.

KAPPEN, H. *On the character and significance of soil acidity.* *In* Zeitschrift für Pflanzenernährung und Düngung, pt. A, v. 3, p. 209–218.

The author discusses the formation and the action of hydrolytical acidity, exchange acidity, and the decomposition of neutral salts.

RIPPEL, A. *The significance of the hydrogen-ion concentration for the micro-organisms and for their activities in the soil.* *In* Zeitschrift für Pflanzenern-ährung und Düngung, pt. A. v. 3, p. 221–227.

It is concluded that part of the microbiological processes in the soil progress in a similar way within certain limits of the hydrogen-ion concentration. This may be due either to a far reaching adjustment of the microorganisms concerned or to the similar biological character of the various species present. Large differences, however, are marked on the alkaline side by increased mineralization (favoring the development of bacteria) and on the acid side by increasing conservation (favoring the development of fungi).

SOIL PHYSICS

RAETHER, A. 1924. *Laws of the capillary rise of soil water.* Thesis, Königsberg.

1. The water rise must be divided into two movements depending on the alternation between narrow and wide spaces; namely, the capillary rise with complete filling, and the funicular rise with more and more incomplete filling of the capillaries. 2. The capillary rise takes place according to the principles involved in the rise in cylindrical capillary glass tubes. 3. In soils mixed according to percentages, the radii (r) of the capillaries decrease with increasing admixtures of fine soil (x) according to the equation: $\log (r - b) = \log (a - b) - c. x - 4$. The varying degrees of wetting play an important rôle in the height of the rise, and in soils mixed according to percentages it also follows a simple logarithmical function.

BREMER, O. 1924. *Studies on the ease of cultivation of various soils.* Thesis, Königsberg.

Hygroscopical soils saturated with water are easiest to cultivate; the resistance to cultivation increases with increasing water content and decreasing air volume. This corroborates the results obtained by Zander and Born. Less labor is required only when the formation of menisci is diminished by higher water content. In mixtures of sand with peat or loam soils, the ease of cultivation increases with increasing amounts of that constituent which causes the greatest air space formation; however, this increase does not take place regularly. The increase is larger when the amount of peat or loam is greater than sand.

BIMSCHAS, J.   1924.   *The water transport through the soil and its relation to the hygroscopicity of various kinds of soils.*   Thesis, Königsberg.

The water transport through loam or peat soil mixed with increasing amounts of sand takes place according to the equation:

$\log (y - i) = \log(a - i) - c.x.$

$a =$ amount of water transported per time unit through pure sand.

$i =$ amount of water transported per time unit through the pure loam or peat soil.

$y =$ amount of water transported per time unit through the sand soil mixture.

$x =$ the quantity of soil in percentages of the soil-sand mixture.

$c =$ factor of proportions.

It was found that in pure soils the water transport changes with the size of the particles.

If a uniform water transport is to be obtained, especially in the case of soil-sand mixtures, attention must be paid to the wetting, the mixing, and the size of the particles of both constituents.

NOLTE, O., AND SANDER E.   1924.   *On the influence of salt solutions on the soil.*   *In* Landwirtschaftlichen Versuchs-Stationen, v. 52, p. 219–225.

In connection with earlier studies an analogy is observed between soil permeability curves obtained from the action of salt solutions of various valencies and the curves of their hydrogen-ion concentrations.   NaCl, LiCl, KCl, rock crystal and KCl, $BaCl_2$, $CaCl_2$, $MgCl_2$, $BeCl_2$, and $FeCl_3$ were studied.

INFLUENCE OF CARBON DIOXIDE OF ATMOSPHERE AND OF SOIL ON PLANT GROWTH

REINAU, E.   1924.   T*he significance of carbon dioxide in atmosphere and soil on crop production.*   *In* Die Technik in der Landwirtschaft, v. 5, pt. 5, p. 95–103.

Soil humus is considered to be the foundation of crop production, because its atmospherical and bacterial decomposition supplies the soil continuously with carbonic acid.   It is claimed that the 0.03 per cent of carbon dioxide present in the atmosphere is insufficient for plant production and that the main part of the carbon dioxide required by the plants is supplied by the soil.   From measurements taken with the apparatus of Petterson and Louden, the following is concluded:

The maximum of carbon dioxide is present a few decimeters above the soil surface; a minimum is present at the upper boundary of the vegetation; and an average is found 1.5 to 2.5 meters above the ground.   The observations, however, are too uncertain for the drawing of such far reaching conclusions.

REINAU, E.   1924.   *Is carbon dioxide a climatological growth factor?*   *In* Zeitschrift für Pflanzenernägrung und Düngung, pt. A, no. 3.

The author is opposed to Mitscherlich's work on the carbon dioxide fertiliz-

ing problem, and attacks especially Janert's work (1923, p. 178) though partially in an unessential way. He claims to be the first to point out that the efficiency of small quantities of carbon dioxide is increased by strong irradiation. Although the plant growth actually can be influenced, according to this investigator, by measurements taken in the field, he objects to the designation of carbon dioxide as a climatological growth factor, basing his objections on his so-called carbon dioxide remainder theory (Kohlensäureresttheorie).

REINAU, E. 1924. *Where do the German harvests originate? A contribution to soil carbon dioxide.* *In* Die Technik in der Landwirtschaft, v. 5, pt. 10, p. 182–196.

The author tries to construct the required fundamentals for his carbon dioxide theories; these, however, are only working hypotheses, since until now he has not been able to give proof by means of demonstrative experimental data. He tries to prove that the legumes take a special place because they are more able to make use of the soil carbon dioxide. He draws attention to the significance of water for the energy transformation (of the sunlight) as well as for its influence on soil respiration. With regard to the carbon dioxide absorption from the atmosphere by the various plants, and to their cultivation methods, the author says:

Woods and meadows are considered to be carbon dioxide fixing vegetations, the grains are on the boundary, and legumes, rather than take up a new supply, make use of the carbonic acid escaping from their systems. The other green manuring plants are important in the agricultural cycle of carbon dioxide because of their conserving power.

The author warns against exhausting the soil of carbon dioxide and states that it should be returned.

REINAU, E. 1924. *Critical remarks on the action law of the growth factors in fertilizing with carbon dioxide.* *Iu* Zeitschrift für Angewandte Botanik, v. 60, no. 3., p. 361–394.

Basing his statements on his greatly propagated hypothesis, the author criticizes the work of Janert and Spirgatis in a way which shows his lack of knowledge of soil science and plant physiology. Moreover, his criticism gives proof of his ignorance of the literature on the subject and of considerable amount of experimental data therein presented. His attack against Mitscherlich is performed in such an unscientific way, that a further discussion would be out of place here.

BORNEMANN. 1924. *Carbon dioxide nutrition of cultivated plants.* *In* Die Umschau, v. 28, no. 45, p. 872–874.

The author, agreeing with Spirgatis, states that no experiments have shown satisfactorily that maximum yields are obtained by normal carbon dioxide content of the air and normal illumination. He bases upon his own experiments the statement that the plants make use of the carbon dioxide diffusing from the

soil and that this actually accelerates the growth.   Therefore, it is claimed that carbon dioxide is of great value as a fertilizer in practical farming.

LEMMERMANN, O., AND KAIM H.   1924.   *The carbon dioxide contents of the air above manured and unmanured soils.   In* Zeitschrift für Pflanzenernährung und Düngung, pt. B, no. 1.

It is demonstrated by pot and field experiments that the carbon dioxide content of the air over a manured soil is not larger than over an unmanured soil. Bornemann, however, claims that even small applications of manure increase the carbon dioxide content of the air.

HASELHOFF, E., AND LIEHR, O.   1924.   *The carbon dioxide content of the soil air.   In* Landwirtschaftlichen Versuchs-Stationen, v. 52, no. 1–2, p. 60–72.

The authors reach the conclusion that the carbon dioxide content of the soil air is higher in the deeper than in the upper layers, although an increase with the temperature was noticed in the upper layers.   Relationship between carbon dioxide content and rainfall or nitrogen fertilizing was not observed.   Distinct differences were not observed during the spring on manured, green manured, and fallowed field plots.   In June, however, a higher carbon dioxide content of the soil air was noticed on the carrot-bearing plots than on the unplanted plots, but the carbon dioxide content of the green manured plots (seradella and peas) was still higher.

FURTHER SOIL STUDIES

POPOFF, M.   1924.   *Fertilizing, fertilizers, and cell stimulation.   In* Zellstimulationsforschungen, v. 1, no. 1, p.   117–128.

The author explains the action of Bertrand's and Stutzer's catalytic fertilizers (manganese salts) as stimulating the germination during rainfall.   A sharp distinction is made between the stimulating action on the seed germination on the one hand, and the nutritive action on the other hand.   Here the question may be raised how to draw the line between the after effect of the stimulation and the fertilizing action.

MITSCHERLICH, EILH. ALFRED.   1924.   *The determination of the fertilizer requirements of the soil.*   Edited by Paul Parey, Berlin.

The author gives a review of his studies on the action law of the growth factors and includes directions for the determination of the nutrient content of the soil by means of pot and field experiments.   This method is being used so largely that in Eastern Prussia only 10,000 pot experiments have been carried on during the last year.

BLANCK, E., AND ALTEN, F.   1924.   *Contributions to the characterization and discrimination of "Roterde."   In* Landwirtschaftlichen   Versuchs-Stationen, v. 53, p. 41–72.

Their quantities of Al_2O_3 and Fe_2O_3 in combination with their hydroscopic-

ity determinations seemed to enable the authors to distinguish between Mediterranean and tropical "Roterde." Thus it may be possible by their chemical properties to characterize on the one hand "terra rossa," "Blutlehme," and "Bohnerztone," and on the other hand the tropical "Roterde" and laterites. This would not be possible by the Bausch analysis only.

BLANCK, E., AND ALTEN, F. 1924. *Experimental contributions to the formation of Mediterranean "Roterde." In* Landwirtschaftlichen Versuchs-Stationen, v. 53, p. 73–90.

In view of the earlier studies of Blanck, the authors assume that "Roterde" are formed on the top of lime or dolomite formations. Of the older formations marble was found to be most easily soluble in carbon dioxide containing water; dolomite, much less soluble; and magnesite, the least soluble. From a study on the influence of humus solutions on solutions of iron, the authors conclude that in the presence of lime, iron can be held in solution by the colloidal action of humus substances. Experiments were performed on the influence of iron solutions on limestone, dolomite, and magnesite both in presence and in absence of protecting humus colloids.

BLANCK, E., AND GIESECKE, F. 1924. *On the influence of earthworms on the physical and biological properties of the soil. In* Zeitschrift für Pflanzenernährung und Düngung, pt. B, no. 5.

The influence of the activity of earthworms on loam, sand, and compost soil was studied. It was found that in all three cases the nitrification was increased, although a decrease was noticed in the putrefaction power of the soil. The earthworms increased the internal soil area (measured by Mitscherlich's method of hygroscopicity determination and by Atterberg's method of mechanical soil analysis) and thus indirectly, the water capacity of the soil.

THE INFLUENCE OF HYDRATION ON THE STABILITY OF COLLOIDAL SOLUTIONS OF SOILS

L. C. WHEETING

Michigan Agricultural Experiment Station

The investigations of Jones (4, 5) and his co-workers concerning the existence of hydrates in solutions of salts in different solvents have shown that ions in solution attract to themselves a number of molecules of water, which appears to exist as an *ionic sphere* in which the ion is a nucleus with the water molecules grouped around it. The size of the sphere is determined by the hydrating power of the salt in question, so that ions with high hydrating power exhibit low migration velocities and affect the freezing point in a definite way by removing water from the rôle of solvent.

Thus KCl with low hydrating power is one of the best conductors of electric current; NaCl with an average hydrating power of 2 molecules is a less efficient conductor; and $Al_2(SO_4)_3$, a highly hydrated salt, is quite inefficient in this respect. It is supposed that in the case of KCl the ionic spheres are small and, therefore, move easily through the solvent, but are large in the case of $Al_2(SO_4)_3$ and hence meet with more resistance within the solvent. The removal of water from the rôle of solvent is of highest interest. The effect of mixing salts with high hydrating power and salts of low hydrating power was also investigated by Jones. It was found that a salt of high attractive force for water could reduce the amount of water held by the less strongly attractive salt, thus bringing about a dehydrating effect on one salt, while the other salt satisfies its greater attractive force.

A third interesting point in Jones' work is brought out in connection with dilution. The more dilute a salt solution becomes, the greater is the hydrating power of each individual ion. These points may be summarized as follows:

1. Ions in solution possess hydrating powers.
2. Ions with highest valence are the strongest hydrate formers.
3. Ions with high hydrating power, when mixed with ions of low hydrating power dehydrate the latter.
4. Ions in dilute solution hold more water of hydration than ions in more concentrated solution.

Burton (2) has shown and Lewis has made a like statement but somewhat modified, that a colloidal particle possesses a charge several thousand times greater than that possessed by a single ion. Therefore, the ion manifestly could not act as a nucleus for the condensation of colloidal particles, and

valence must be effective in some other manner than through electrical neutralization. However, Hardy, Schulze and others have shown that in general the higher the valence of an ion the greater is its precipitating action. Since Jones has shown the effect of valence on hydration, it would seem logical to expect some degree of correlation between hydration effects and flocculation effects. Martin Fischer (3) has observed these valency effects in connection with the swelling of soap solutions.

In certain work carried on in connection with colloidal properties of soil profiles, it has been shown by means of heat of wetting measurements that colloids extracted from unweathered soil horizons, which contain quantities of salts, are quite inactive and give proportionally low heats of wetting. Colloids extracted in the same way from weathered horizons, containing small quantities of salt, are highly active. Since heat of wetting is mainly due to formation of hydrates, it would appear that colloids as well as ions have different powers of hydration; therefore, the investigation of mixtures of salts and colloids was begun. Two salts with strong flocculating power as well as strong hydrating power, and one salt with a strong deflocculating power and low hydration effect were used and comparison was made with a water-treated colloid alone as a check. The hydrate water was measured by means of dilatometers, using the method explained by Bouyoucos (1). A temperature of $-4°C.$ was employed in all work. By means of a pipette, 2 cc. of concentrated colloidal sludge was measured into a dilatometer and variable treatments of 1 cc. each were added. The dilatometer containing 2 cc. of colloidal sludge and 1 cc. of water was used as a check. When pure salt solutions were treated in a similar manner, only 0.1 cc. at the most was not freezable. These corrections have been made on the results, which are shown in table 1.

In every case, the check dilatometer containing a total measured volume of 3 cc. including a definite weight of colloidal particles, allowed more than 3 cc. to freeze. A portion of the water which was measured out must, therefore, be more compact and of greater density than normal water. The colloidal material appears to bring about a condensation of water molecules in some loosely held condition and the temperature of $-4°C.$ is sufficiently severe to break down at least a portion of this structure, thereby liberating free water in excess of the volume measured out in the beginning.

A greater quantity of water can be frozen in the case of treatments with strongly hydrated salts of strong flocculating powers. It appears to be possible further to reduce the combined water by such treatments, thus liberating some hydrate water, which can be frozen. In all the cases reported this release of hydrated water was observed. Flocculation was also observed taking place immediately after mixing the colloidal sludge and the salt solution.

When a salt solution with a strong deflocculating action is studied, the reverse of the above is found. In these cases, the amount of freezable water is reduced and must, therefore, exist in some combined form, such as water of hydration. There is distinct evidence of greater dispersion after treatment with this salt, a fact which is well established in soils studies.

There is, then, a definite correlation existing between flocculation effects and the amount of water of hydration held by the colloids.   Evidently when they are in a dispersed condition, they hold more combined water than when flocculated.   It is also apparent that there is a critical point in the degree of hydration of colloids, below which they are unstable, and above which they are stable.   Flocculation may be brought about by any treatment which will reduce below the critical point the water of hydration held by the colloid. Stabilization results from increases in the hydrate content.   Puri and Keen (6) have concluded that the influence of electrolytes on soil suspensions is

TABLE 1

Volume of free water present at −4°C. under various treatments

HORIZON	WEIGHT OF COLLOID IN 2 CC. SLUDGE	DISTILLED WATER*	0.2 N Na$_2$CO$_3$*	0.2 N Pb(NO$_3$)$_2$*	0.2 N Al$_2$(SO$_4$)$_3$
			Brookston loam		
	gm.	cc.	cc.	cc.	cc.
A$_1$	0.1320	3.33	2.96	3.40	3.35
A$_2$	0.1670	3.30	3.22	3.40	3.40
B	0.3380	3.30	3.12	3.40	3.40
C	0.3190	3.33	3.02	3.40	3.55
			Ontonagon clay loam		
A$_1$	0.0950	3.22	3.05	3.44	3.44
A$_2$	0.0940	3.27	3.10	3.65	3.60
B	0.2210	3.11	2.70	3.33	3.30
C	0.3540	3.11	2.90	3.20	3.24
			Napanee silt loam		
A$_1$	0.0500	3.40	3.11	3.83	3.77
A$_2$	0.0820	3.23	2.94	3.39	3.30
B	0.0890	3.12	2.70	3.27	3.32
C	0.1340	3.38	2.85	3.50	3.70

* One cubic centimeter added to 2 cc. colloidal solution.

not a sharp flocculation or deflocculation but a gradual and progressive action, as the concentration is increased.   This same gradual action has been observed by Jones in connection with mixtures of salt solutions.

The thick, concentrated colloidal materials used in the preceding work invariably flocculated upon standing, leaving a clear supernatant liquid above. If, however, a given volume was increased by the addition of pure water, using 2, 4, 8, 16 times as much water as colloidal material, the particles became definitely stable when sufficient water was supplied.   Evidently the volume of dispersive medium is important.   Since Jones found that increasing dilu-

tion increased the hydrate water per ion, it would seem reasonable to expect the same relationship in dealing with colloidal particles, and that as soon as they become sufficiently hydrated, they also become stable.

It is, therefore, evident that at least in the case of negatively charged soil colloids, dispersed in water, the state of dispersion or flocculation is governed by the quantity of water of hydration held by the particles. Any treatment which changes the equilibrium will change the stability of the colloid. The protective action of emulsoid colloids is very likely due to the fact that such colloids have strong hydrating powers and are, therefore, able to resist the dehydrating effects of many electrolytes.

It is believed that a consideration of the degree of hydration of colloidal particles will clear up many points that have been quite obscure, in connection with stability of colloidal solutions.

REFERENCES

(1) Bouyoucos, G. J. 1917 The measurement of the inactive or unfree moisture in the soil by means of the dilatometer method. *In* Jour. Agr. Res., v. 8, p. 195.

(2) Burton, E. F. 1921 Coagulation of colloidal solutions of electrolytes. *In* Univ. Toronto Studies, Chem. Ser. 120.

(3) Fischer, Martin H. 1922 Ternary systems and the behavior of protoplasm. *In* Science, v. 48, p. 143.

(4) Jones, Harry C. 1907 Conductivity and viscosity in mixed solvents. Carnegie Inst., Washington. Pub. 80.

(5) Jones, Harry C. 1913 The freezing point lowering, conductivity and viscosity of solutions of certain electrolytes in water, alcohol, acetone, and glycerol and in mixtures of these solvents with one another. Carnegie Inst., Washington. Pub. 180.

(6) Puri, A. N., and Keen, A. B. 1925 The dispersion of soil in water. *In* Jour. Agr. Sci. v. 15, pt. 2, p. 147.

ALKALI STUDIES: III. TOLERANCE OF BARLEY FOR ALKALI IN IDAHO SOIL[1]

RAY E. NEIDIG AND H. P. MAGNUSON

Idaho Agricultural Experiment Station

Tolerance studies of certain crops for alkali salts in Idaho soil have been reported in the two previous papers (6, 7). The growth of wheat was carried through two crops before the experiment was concluded. When the results were studied, it appeared that data secured on more than two crops would be valuable, hence, in the series on barley and oats, four crops were grown. Data was desired not only on the crop growth as affected by alkali salts, but also on the amount of salts that could be recovered from this soil after each cropping.

Lipman and Gericke (3) were the first to call attention to the positive indications of antagonism between anions as affecting barley yields on a clay adobe soil. Their observations were based upon two successive crops of barley. This is one of the few akali studies in which the conclusions are based on more than one crop growth. Later the same authors (4) published results on a four-crop series of barley in which certain alkali concentrations were used singly and in combinations of the three salts. This study pertained to the effect of heavy manurial applications as an ameliorating influence on alkali soil.

GENERAL DESCRIPTION OF THE EXPERIMENTS

The plants were grown in 4-gallon pots in the greenhouse. The alkali concentrations were made up on the basis of anhydrous soil. The mixing of the soil and alkali salts was similar to that in the wheat series which has been described in an earlier paper (6). The soil used was the same as that used in our earlier tolerance studies. The alkali salts employed were sodium chloride, sodium carbonate and sodium sulfate, singly and in varying combinations. Duplicate treatments were made in every case and although there are some abnormalities appearing in the duplicates, they probably represent in general the trend of the effect of alkali salts on crop yield in this particular soil. Discrepancies in duplicate yields are more general when the salt concentrations closely approach or are at the critical concentration for the crop. In such cases no growth may be secured in one pot, while in its duplicate a good growth

may take place.   As mentioned in a previous publication (6), there is a point where a very minor difference in alkali concentrations in the soil will markedly affect plant growth.

Only the average yields of the crops are reported in this paper, as these are considered more representative of the average conditions.   The authors feel that in data presented in all alkali tolerance studies the general trend of results should be considered instead of absolute values being placed on any particular portion of the data.   A critical study of the data in this paper will show the reader that certain general effects of alkali salts in this soil are evident.

The yield in grams of dry matter of the crops on the check soil is as follows: First crop, 29.0; second crop, 32.6; third crop, 9.7; fourth crop 18.0.   For the sake of brevity only the percentage yield, considering the check as 100 per cent, is given in the table.

DESCRIPTION OF THE FOUR BARLEY CROPS

Crop 1

On July 5, 1922, twelve seeds of white winter barley were planted in each pot.   Germination data were secured.   When the plants were established, they were thinned to seven per pot.   A significant feature of this crop of barley was the profuse stooling and the resulting bushiness of the plants. The weather was very hot for a short period and the temperature exceeded 100°F. for several consecutive days in the greenhouse.   After this warm period the plants seemed to lose their vigor and very few heads were produced; this crop was harvested on October 27, 1922, and the total dry weight of crop determined.   The type of barley and the period of extremely warm weather contributed somewhat to the poor development of this crop.   The weight of dry matter is comparable even though it did not mature a crop.

Crop 2

On October 30, 1922, twelve seeds of Trebi barley, which is a spring variety, were planted.   The usual germination data were collected and the plants thinned to five per pot.   This series of plants developed slowly because of the lack of sunshine, which is so common in the late fall at the Station.   Stooling, although rather pronounced, was not so profuse as in the first crop.   The growth was very slow during the months of December and January.   In February a renewed stimulation of growth took place and appeared to be normal after this time.   The plants commenced to head out in April and were harvested on June 25, 1923.

Crop 3

Similarly the third crop was planted on June 25, 1923.   As this crop also showed evidence of excessive stooling, some of the shoots were removed to prevent the development of too bushy plants, leaving each plant one strong stalk.   This series grew under favorable conditions until the rainy season

began in September with the consequent lack of sunshine. The plants slackened their growth, new shoots began to appear, and the development of heads was retarded. The heads filled very poorly and in many cases did not produce grain. The crop was harvested on December 8, 1923, although at that time some of the later shoots were still green.

Crop 4

The soils were dried and cultivated thoroughly in the pots and were permitted to remain in this fallow condition for three months before planting the fourth crop. This time was permitted to elapse in order to secure a normal growing season for the final crop of barley, since barley seems to develop reluctantly under our greenhouse conditions. On March 4, 1924, the fourth crop was planted and the data on germination were collected. At this time the number of plants was reduced to five for each pot. With this crop little stooling was observed and the plants developed very satisfactory heads which were rather well filled.

In this series, the plants grown on the soils without alkali additions showed a decided evidence of lack of plant-food. This condition might reasonably be expected since four continuous crops have been grown on the same soil without fertilizer treatments. Since all the treatments were grown under similar conditions, it is not considered that this feature introduces an error in the results. The results of crop yield are calculated in per cent of the check, hence any difference noted between the alkali salt treated soils and the checks should generally be attributed to the alkali additions. Several concentrations were omitted in the fourth crop of barley. The reason for discontinuing certain light and certain extremely heavy concentrations of salts was chiefly to reduce the magnitude of the treatments and the work connected therewith. The data shows that certain concentrations, particularly the lesser ones, might have been profitably continued through the fourth crop. These might have been of value in explaining some of the fourth crop yields.

EFFECT OF SINGLE-SALT ADDITIONS ON BARLEY

Table 1 contains the data on the effect of additions of sodium carbonate on the yields of barley for four crops.

That sodium carbonate is toxic to the first crop is quite evident from the data. The toxicity increases with increased salt additions. For the growth of barley in this soil, 0.6 per cent addition exceeds the critical concentration of sodium carbonate. Very little difference is noted in the 0.2 per cent and 0.4 per cent additions on the yield of the first crop. The second crop indicates a normal growth with additions as high as 0.4 per cent. Above this concentration barley was a total failure. The third crop showed a yield below the check crops for all concentrations, although the reduction in the 0.2 per cent and 0.4 per cent additions was not great. Some growth took place in the third crop in the 0.6 per cent addition which shows an attempt on the part of the soil

TABLE 1

Soil treatments, salt recovery and crop yield

Single-salt combinations

NUMBER	TREATMENT Na₂CO₃ per cent	NaCl per cent	Na₂SO₄ per cent	FIRST CROP Yield per cent	Na₂CO₃ per cent	Total Na₂CO₃ per cent	NaCl per cent	Na₂SO₄ per cent	SECOND CROP Yield per cent	Na₂CO₃ per cent	Total Na₂CO₃ per cent	NaCl per cent	Na₂SO₄ per cent	THIRD CROP Yield per cent	Na₂CO₃ per cent	Total Na₂CO₃ per cent	NaCl per cent	Na₂SO₄ per cent	FOURTH CROP Yield per cent	Na₂CO₃ per cent	Total Na₂CO₃ per cent	NaCl per cent	Na₂SO₄ per cent
1	Check			100.0	0.000	0.036	0.000	0.007	100.0	0.000	0.034	0.002	0.006	100.0	0.000	0.039	0.000	0.010	100.0	0.000	0.024	0.010	0.010
3	0.2			89.6	0.044	0.108	0.000	0.011	104.0	0.050	0.092	0.000	0.006	92.8	0.028	0.094	0.000	0.009	123.5	0.063	0.136	0.011	0.012
5	0.4			83.0	0.094	0.170	0.000	0.007	100.2	0.096	0.142	0.002	0.006	82.2	0.070	0.152	0.000	0.011	90.2	0.112	0.186	0.002	0.014
7	0.6			23.9	0.173	0.259	0.000	0.008	0.0	0.162	0.214	0.008	0.010	14.3	0.126	0.203	0.000	0.015					
9	0.9			0.0	0.303	0.379	0.000	0.005	0.0	0.237	0.317	0.009	0.011	0.0	0.222	0.292	0.000	0.018					
11		0.2		90.9	0.000	0.033	0.224	0.007	115.7	0.000	0.024	0.167	0.006	62.1	0.003	0.033	0.162	0.009	91.2	0.000	0.024	0.268	0.008
13		0.4		56.2	0.000	0.031	0.326	0.008	166.9	0.002	0.020	0.298	0.005	90.7	0.001	0.029	0.338	0.009					
15		0.8		12.4	0.000	0.033	0.824	0.009	117.4	0.005	0.026	0.561	0.007	9.2	0.000	0.024	0.671	0.009					
17			0.2	88.7	0.000	0.049	0.000	0.205	127.9	0.005	0.025	0.002	0.139	73.4	0.005	0.038	0.003	0.134	84.8	0.000	0.026	0.002	0.315
19			0.4	92.7	0.000	0.043	0.003	0.430	102.9	0.005	0.023	0.000	0.186	84.1	0.000	0.036	0.000	0.303	90.7	0.000	0.021	0.002	0.666
21			0.8	83.5	0.000	0.045	0.000	0.735	119.5	0.000	0.023	0.000	0.606	86.1	0.000	0.031	0.000	0.607					
23			1.2	85.1	0.000	0.049	0.000	1.000	146.5	0.000	0.018	0.000	1.035	79.5	0.000	0.030	0.000	1.074	73.6	0.000	0.018	0.000	1.334
25			1.5	59.3	0.000	0.043	0.000	1.308	126.2	0.000	0.018	0.000	0.981	86.7	0.000	0.027	0.000	1.286					
89			2.4	8.6	0.000	0.044	0.000	2.381	66.7	0.000	0.017	0.000	2.166	0.0	0.000	0.028	0.000	2.250					

to recover from this treatment. This is more plainly seen in the fourth crop where the yield was only slightly below normal for the 0.6 per cent addition, while in the 0.4 per cent addition the fourth crop yield was greater than the check crop.

That there is a gradual adjustment in the soil is shown by the data representing the recoverable salts in the soil after each crop was harvested. Treatment 5, which is the 0.4 per cent addition, shows an initial recovery of 0.17 per cent before the first crop and 0.152 per cent when sampled just previous to planting the fourth crop. Treatment 7, the 0.6 per cent addition, is even more striking, showing 0.259 per cent sodium carbonate recovery before the first crop, 0.214 before the third, 0.203 per cent before the fourth and 0.186 per cent after the fourth crop was harvested. There is a gradual reduction in recoverable carbonate which aids the soil in producing a crop.

Sodium chloride treatments show toxicity in the first crop, the degree of toxicity being in direct relationship to the amount added. The heaviest addition, 0.8 per cent, resulted in a very low yield. All sodium chloride additions are toxic to the first crop. In the second crop all concentrations show stimulated yields over the check crops, 0.4 per cent addition resulting in the largest increase. The third crop shows a toxic effect for all concentrations. Here again the 0.4 per cent addition gives the best yield, although it is below normal. Only the 0.4 per cent concentration was cropped the fourth time, which resulted in a yield below normal. That the 0.8 per cent addition of sodium chloride shows a yield above normal in the second crop is very remarkable when the recoverable salt concentration previous to planting was found to be 0.824 per cent. We offer no explanation at this time for the stimulation of this second crop in the presence of such high recoverable chlorides while the first and third crops were practically failures.

Additions of 0.4 per cent of sodium sulfate to the soil have a tendency to be toxic to the first crop. It was surprising to find this toxicity remaining approximately the same, regardless of the increase in concentrations up to and including 1.2 per cent. Even the concentration of 1.5 per cent yielded a little more than one-half the normal crop. The extreme concentration used, 2.4 per cent, was very toxic.

All sodium sulfate concentrations from 0.2 to 1.5 per cent were stimulating to the second crop. In these treatments, with the exception of lowest addition the increased stimulation occurred in the order of the increasing concentration. The soil had recovered from the excessive addition of 2.4 per cent sodium sulfate to the extent that it gave a yield of 66.7 per cent as much barley as the untreated control soil, while the 1.5 per cent addition gave an increase of 26 per cent above normal.

The third crop of barley in the untreated control soil shows a decreased yield in all concentrations. The yields are remarkably uniform for all treatments from additions of salt of 0.2 to 1.5 per cent, inclusive. The reader's attention is called to the striking similarity of these yields when the salt

recoveries, which vary from 0.134 per cent in treatment 17 to 1.28 per cent in treatment 25, are considered.

The fourth crop yields show results very similar to those in the third. A fourth crop was not grown on all concentrations.

<center>TWO-SALT CONCENTRATIONS</center>

The combinations of salt additions in table 2 are grouped according to a basic sodium carbonate addition with varying amounts of the other two salts.

The effect of increasing amounts of sodium chloride in the presence of low carbonates (0.2 per cent) is to reduce yield in the first crop in the order of increased additions. Here is seen a decided additive toxicity due to sodium chloride. The second crop is stimulated both in the 0.3 and 0.6 per cent sodium chloride additions. The third crop shows a yield slightly lower than the original check soil for the 0.2 per cent sodium carbonate addition. The 0.3 per cent sodium chloride addition does not appear to be toxic in this combination. In the 0.6 per cent addition of sodium chloride the toxic load of the soil becomes too great and results in an almost complete crop failure. Only one treatment under this series was cropped the fourth time, namely, the 0.3 per cent addition of sodium chloride to the 0.2 per cent sodium carbonate. This treatment showed a marked stimulation in the fourth crop. Only the first crop was reduced below the check by the 0.3 per cent sodium chloride addition in the presence of 0.2 per cent sodium carbonate.

With corresponding additions of sodium sulfate, we find again, as in the single sodium sulfate addition, that it makes little difference whether 0.4 or 1.0 per cent salt be added, as long as the sulfate ion is present. In crop 1 there is an added toxicity for all three combinations greater than the sum of toxicities of each component when alone. In crop 2 this is reversed, and a stimulation greater than the sum of the stimulation produced by each salt when alone is observed. The 0.6 per cent sodium sulfate addition produced the highest stimulation, and maintained it through three crops. In crop 4, the additions of 0.4 and 0.6 per cent sodium sulfate reduced the yield to 77 per cent of the check, but the 1.0 per cent addition produced normal growth.

When the 0.4 per cent sodium carbonate application is used as a basic treatment, less toxicity is found with the 0.1 per cent sodium chloride addition than with the 0.2 per cent sodium sulfate in all except the fourth crop and in this case the difference is almost negligible.

Basic treatments of 0.6 per cent sodium carbonate with varying amounts of sodium chloride and sodium sulfate are given. Little need be said of this series since it is a group of miscellaneous treatments in which the toxic load of the high sodium carbonate addition is quite noticeable alone and also in combination with high sodium chloride and sodium sulfate. One treatment, 29, gave a very luxuriant growth of barley in the fourth crop. This seems without apparent explanation since the recoverable carbonates at this time differ very little from the other recoveries which resulted in low yields. It

TABLE 2

Soil treatments, salt recovery and crop yield

Two-salt combinations in which sodium carbonate is the basic treatment

NUMBER	TREATMENT			FIRST CROP					SECOND CROP					THIRD CROP					FOURTH CROP				
	Na$_2$CO$_3$	NaCl	Na$_2$SO$_4$	Yield	Na$_2$CO$_3$	Total Na$_2$CO$_3$	NaCl	Na$_2$SO$_4$	Yield	Na$_2$CO$_3$	Total Na$_2$CO$_3$	NaCl	Na$_2$SO$_4$	Yield	Na$_2$CO$_3$	Total Na$_2$CO$_3$	NaCl	Na$_2$SO$_4$	Yield	Na$_2$CO$_3$	Total Na$_2$CO$_3$	NaCl	Na$_2$SO$_4$
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
3	0.2			89.6	0.044	0.108	0.000	0.011	104.0	0.050	0.092	0.000	0.006	92.8	0.028	0.094	0.000	0.009					
31	0.2	0.3		60.7	0.020	0.073	0.273	0.007	162.7	0.034	0.074	0.217	0.007	102.6	0.024	0.061	0.268	0.013	125.2	0.019	0.065	0.232	0.011
33	0.2	0.6		38.4	0.010	0.064	0.595	0.007	139.0	0.016	0.050	0.499	0.006	10.2	0.015	0.046	0.545	0.010					
47	0.2		0.4	63.9	0.015	0.075	0.011	0.414	138.7	0.042	0.069	0.000	0.302	83.6	0.016	0.070	0.000	0.418	77.0	0.020	0.054	0.000	0.407
49	0.2		0.6	57.1	0.020	0.073	0.003	0.489	165.7	0.026	0.057	0.000	0.494	111.8	0.021	0.064	0.000	0.519	77.1	0.017	0.052	0.000	0.490
51	0.2		1.0	59.0	0.015	0.061	0.000	0.942	155.7	0.032	0.054	0.000	0.665	76.4	0.019	0.059	0.000	0.706	99.6	0.015	0.042	0.000	0.778
5	0.4			83.0	0.094	0.170	0.000	0.007	100.2	0.096	0.142	0.002	0.006	82.2	0.070	0.152	0.000	0.011	123.5	0.063	0.136	0.011	0.012
27	0.4	0.1		75.2	0.075	0.150	0.108	0.009	152.5	0.096	0.137	0.071	0.012	104.3	0.107	0.145	0.074	0.017	108.8	0.103	0.141	0.060	0.018
53	0.4		0.2	55.8	0.080	0.152	0.000	0.200	130.5	0.141	0.164	0.000	0.128	87.7	0.098	0.150	0.000	0.125	120.3	0.079	0.129	0.000	0.138
7	0.6			23.9	0.175	0.259	0.000	0.008	0.0	0.162	0.214	0.008	0.010	14.3	0.126	0.203	0.000	0.015	90.2	0.112	0.186	0.002	0.004
29	0.6	0.1		48.0	0.142	0.221	0.109	0.005	0.0	0.146	0.226	0.114	0.015	84.6	0.132	0.179	0.088	0.017	242.7	0.132	0.162	0.078	0.011
55	0.6		0.2	23.5	0.170	0.253	0.003	0.226	20.6	0.174	0.205	0.000	0.152	11.2	0.128	0.203	0.000	0.178	51.9	0.153	0.192	0.000	0.167
35	0.6	0.6		19.7	0.080	0.153	0.594	0.005	62.5	0.108	0.129	0.584	0.008	3.0	0.082	0.122	0.539	0.013					
59	0.6		0.8	8.4	0.101	0.194	0.000	0.564	0.0	0.141	0.175	0.000	0.539	0.0	0.122	0.178	0.000	0.564					

should be mentioned, however, that the third crop had partially recovered from the effect of the treatment, but the extreme growth of this fourth crop was unexpected.

When the 0.6 per cent sodium carbonate is considered as the check, we have a 20 per cent yield for the 0.2 per cent sodium sulfate addition and 62 per cent for 0.6 per cent sodium chloride addition in the second crop. In this case, the addition of 0.1 per cent sodium chloride seems to be too small an amount to produce a stimulating action over the 0.6 per cent sodium carbonate, while 0.6 per cent sodium chloride is high enough to produce this effect to a certain extent. The 62 per cent growth in crop 2 might well be considered the result of the stimulation due to the effect of 0.6 per cent sodium chloride partially overcoming the toxic effect of the sodium carbonate addition. The soil has a tendency to overcome the toxicity of the sodium carbonate and produce a partial yield in the fourth crop. The yields of the fourth crop for treatments 7 and 55 are strong evidence of the power of this soil to overcome toxicity. This recovery is not possible when the toxic load becomes too great. In fact these concentrations may well be considered the upper limit of salt addition which this soil can withstand.

Table 3 shows the effect of varying additions of sodium chloride and sodium carbonate with definite amounts of sodium sulfate. In the 0.2 per cent sodium sulfate treatment, the addition of 0.4 per cent sodium carbonate tends to be stimulating in the second and fourth crops, quite toxic in the first crop and less toxic in the third crop. In combination with 0.2 per cent sodium sulfate, the 0.6 per cent addition of sodium carbonate is markedly toxic and 0.8 per cent sodium carbonate is entirely prohibitive to crop growth.

Treatments of 0.2 per cent sodium sulfate plus treatments of chlorides are toxic in the first crop and very stimulating to the second, even with the 0.6 per cent sodium chloride treatment. The third crop approaches normality for the 0.3 per cent sodium chloride addition, and the 0.6 per cent addition gives a yield of 77 per cent normal. In the fourth crop the 0.3 per cent sodium chloride addition produces a yield of 83 per cent of the normal yield. A fourth crop of barley was not grown on the 0.6 per cent sodium chloride treatment.

A treatment of 0.4 per cent sodium sulfate plus 0.1 per cent sodium chloride was more stimulating to crop growth than 0.4 per cent sodium sulfate plus 0.2 per cent sodium carbonate. In this series the beneficial effect of small additions of sodium chloride to a medium concentration of sodium sulfate is noticeable. The chloride-sulfate combination shows less toxicity in the first crop and greater stimulation in the succeeding crops.

The 0.8 per cent sodium sulfate being considered as the basic addition, very little change from the single additions of 0.2 and 0.4 per cent sodium sulfate is noted. The addition of high sodium carbonate (0.6 per cent) produces too heavy a toxic load for the soil to overcome and a crop failure results. The addition of 0.6 per cent sodium chloride produces a yield of 32 per cent in the first crop with stimulation in crop 2 nearly equal to that of treatments 41

TABLE 3
Soil treatments, salt recovery and crop yield

NUMBER	TREATMENT Na₂CO₃ (per cent)	TREATMENT NaCl (per cent)	TREATMENT Na₂SO₄ (per cent)	FIRST CROP Yield	Na₂CO₃	Total Na₂CO₃	NaCl	Na₂SO₄	SECOND CROP Yield	Na₂CO₃	Total Na₂CO₃	NaCl	Na₂SO₄	THIRD CROP Yield	Na₂CO₃	Total Na₂CO₃	NaCl	Na₂SO₄	FOURTH CROP Yield	Na₂CO₃	Total Na₂CO₃	NaCl	Na₂SO₄
17			0.2	88.7	0.000	0.049	0.000	0.205	127.9	0.005	0.025	0.002	0.139	73.4	0.005	0.038	0.003	0.134					
53	0.4		0.2	55.8	0.080	0.152	0.000	0.200	130.5	0.141	0.164	0.000	0.128	87.7	0.098	0.150	0.000	0.125	120.3	0.079	0.129	0.000	0.139
55	0.6		0.2	23.5	0.170	0.253	0.003	0.226	20.6	0.174	0.205	0.000	0.152	11.2	0.128	0.203	0.000	0.178	51.9	0.153	0.192	0.000	0.168
57	0.8		0.2	0.0	0.263	0.378	0.048	0.589	0.0	0.217	0.274	0.000	0.154	0.0	0.162	0.241	0.001	0.170					
41		0.3	0.2	77.3	0.000	0.027	0.304	0.223	166.0	0.000	0.015	0.217	0.150	94.2	0.000	0.028	0.245	0.189	83.4	0.000	0.020	0.220	0.187
43		0.6	0.2	55.2	0.000	0.024	0.601	0.203	163.9	0.000	0.015	0.352	0.173	77.4	0.000	0.027	0.328	0.180					
19			0.4	92.7	0.000	0.043	0.003	0.430	102.9	0.005	0.005	0.026	0.186	84.1	0.000	0.036	0.000	0.303	84.2	0.000	0.026	0.002	0.315
37	0.1		0.4	77.1	0.000	0.029	0.110	0.388	131.5	0.000	0.021	0.055	0.293	103.5	0.001	0.031	0.082	0.332	111.0	0.001	0.030	0.082	0.318
47	0.2		0.4	63.9	0.015	0.075	0.011	0.414	138.7	0.042	0.069	0.000	0.303	83.6	0.016	0.070	0.000	0.418	77.0	0.020	0.054	0.000	0.407
21			0.8	83.5	0.000	0.045	0.000	0.735	119.5	0.000	0.023	0.000	0.606	86.1	0.000	0.031	0.000	0.607	90.7	0.000	0.021	0.002	0.666
59	0.6		0.8	8.4	0.101	0.194	0.000	0.564	0.0	0.141	0.175	0.000	0.539	0.0	0.112	0.178	0.000	0.564					
45		0.6	0.6	31.9	0.000	0.035	0.508	0.605	156.5	0.000	0.020	0.342	0.489	19.5	0.000	0.024	0.370	0.428					
39		0.1	0.8	72.9	0.000	0.032	0.098	0.820	158.5	0.000	0.014	0.055	0.640	123.2	0.002	0.031	0.067	0.701	110.1	0.000	0.031	0.059	0.679

All values expressed in per cent.

and 43.   The yield falls to 19 per cent in crop 3.   This shows the tendency of crop 2 to withstand a very heavy toxic load of sodium chloride in combination with sodium sulfate.

With a small addition of sodium chloride to high sodium sulfate in treatment 39, there is a slightly greater stimulation in crop 2 than in treatment 45, with high sodium chloride.   The yield is also higher than in treatment 36, where less sodium sulfate is added.   These yields indicate some soil reaction producing stimulation, which can hardly be classed as antagonism in the sense usually understood.   The same situation appears in the case of single sulfate additions, where the addition of more of the same salt, namely, sodium sulfate, produces increased yield up to the addition of 1.2 per cent.

In either case, the stimulating influence of chlorides in crop 2 is commonly stronger in combinations with sulfates than with carbonates, and is always present if the amount of salts does not exceed the critical concentration.

If the sodium chloride additions are considered as the basic treatment in combination with other salts, in table 4, difficulty is found in making comparisons with the two-salt treatments in view of the fact that there are no corresponding single salt additions for the chlorides.   A 0.1 per cent sodium chloride treatment was not included in the experiment, hence it is necessary to use the 0.2 per cent treatment as a basis in making comparisons with the salt combinations with 0.1 per cent sodium chloride.   In the addition of 0.1 per cent sodium chloride with high sodium carbonate and sodium sulfate, 0.6 per cent sodium carbonate shows a 50 per cent reduction in crop 1, a total failure in crop 2, a partial recovery in crop 3, and an abnormal stimulation in crop 4.   There appears to be no logical explanation for this abnormality in the fourth crop yield.   However, 0.1 per cent sodium chloride, with 0.8 per cent sodium sulfate, does not reduce the first crop as much as with the corresponding addition of sodium carbonate and maintains a high stimulation throughout the oterh three crops.

With increasing additions of sodium chloride, there is greater decrease in the first crop and correspondingly higher stimulation in crop 2 with a tendency toward normal growth in crops 3 and 4.   The addition of 0.2 per cent sodium sulfate produces increased growth in all crops; 0.2 sodium carbonate has a similar effect maintaining a decided stimulation above normal in crops 3 and 4.   Unfortunately, we do not have a treatment with 0.6 per cent sodium chloride alone.   Regardless of whether 0.4 or 0.8 per cent sodium chloride treatment is used as a basic comparison, it is evident that the addition of sulfate in the small amount of 0.2 per cent decreases the toxicity of sodium chloride rather than increases it in crop 1.   No such influence is noted with the sodium carbonate addition of 0.2 per cent.   In both cases, however, the stimulation in crop 2 is greater than for the chloride treatment alone.   Where 0.6 per cent sodium chloride is added in company with sodium carbonate, a very high percentage of toxicity follows.   Even with this high concentration, a yield of 62 per cent of the normal is found in the second crop.

TABLE 4

Soil treatments, salt recovery and crop yield

Two-salt combinations in which sodium chloride is the basic treatment

(all values in per cent)

NUMBER	TREATMENT			FIRST CROP					SECOND CROP					THIRD CROP					FOURTH CROP				
	Na_2CO_3	$NaCl$	Na_2SO_4	Yield	Na_2CO_3	Total Na_2CO_3	$NaCl$	Na_2SO_4	Yield	Na_2CO_3	Total Na_2CO_3	$NaCl$	Na_2SO_4	Yield	Na_2CO_3	Total Na_2CO_3	$NaCl$	Na_2SO_4	Yield	Na_2CO_3	Total Na_2CO_3	$NaCl$	Na_2SO_4
11		0.2		90.9	0.000	0.033	0.224	0.007	115.7	0.000	0.024	0.167	0.006	62.1	0.003	0.033	0.162	0.009					
27	0.4	0.1		75.2	0.075	0.150	0.108	0.009	152.5	0.096	0.137	0.071	0.012	108.3	0.107	0.145	0.074	0.017	108.8	0.106	0.141	0.106	0.018
29	0.6	0.1		48.0	0.142	0.221	0.109	0.005	0.0	0.146	0.226	0.114	0.015	84.6	0.132	0.179	0.088	0.017	242.7	0.132	0.162	0.078	0.011
37		0.1	0.4	77.1	0.000	0.029	0.110	0.388	131.5	0.000	0.021	0.055	0.293	103.5	0.001	0.031	0.082	0.332	111.0	0.000	0.030	0.082	0.318
39		0.1	0.8	72.9	0.000	0.032	0.098	0.820	158.5	0.000	0.014	0.055	0.640	123.2	0.002	0.031	0.067	0.701	110.1	0.000	0.031	0.059	0.679
13		0.4		56.2	0.000	0.031	0.326	0.008	166.9	0.002	0.020	0.298	0.005	90.7	0.001	0.029	0.338	0.009	81.2	0.000	0.024	0.268	0.008
31		0.2		60.7	0.020	0.073	0.273	0.007	162.7	0.034	0.074	0.217	0.007	102.6	0.024	0.061	0.268	0.013	125.2	0.019	0.065	0.232	0.011
41	0.2	0.3	0.2	77.3	0.000	0.027	0.304	0.223	166.0	0.000	0.015	0.217	0.150	94.3	0.000	0.028	0.245	0.189	83.4	0.000	0.020	0.220	0.187
15		0.8		12.4	0.000	0.033	0.824	0.009	117.4	0.005	0.026	0.561	0.007	9.2	0.000	0.024	0.671	0.009					
33	0.2	0.6	0.2	38.4	0.010	0.064	0.595	0.007	139.1	0.016	0.050	0.499	0.006	10.2	0.015	0.046	0.545	0.010					
43		0.6	0.2	55.2	0.000	0.024	0.601	0.203	163.9	0.000	0.015	0.352	0.173	77.4	0.000	0.027	0.328	0.180					
35	0.6	0.6		19.7	0.080	0.153	0.594	0.005	62.5	0.108	0.129	0.584	0.008	3.0	0.082	0.122	0.539	0.013					
45		0.6	0.6	31.9	0.000	0.035	0.508	0.605	156.5	0.000	0.020	0.342	0.489	19.5	0.000	0.024	0.370	0.428					

With 0.6 per cent sodium sulfate, the second crop shows a stimulation nearly the same as 0.4 per cent sodium chloride alone, and far above the 0.8 per cent sodium chloride or 0.8 per cent sodium sulfate. It is noticeable that at this high concentration of salt, there may be very great differences in plant growth between the duplicate pots for a given treatment, especially where the amount of salts is near the critical concentration for any salt or combinations of salts. At this point yields may vary greatly for no readily apparent cause. This situation also seems to hold true for the stimulation in the second crop. There is increasing toxicity in crop 1, with increasing stimulation in crop 2, accompanying higher salt additions until a high mark is reached. A sudden and extensive drop in yield to normal or below is often found. This sudden drop is most pronounced with increasing concentrations of sodium carbonate and is almost as great with sodium chloride.

A similar situation exists in the case of the third and fourth crops. As the concentration of salts increases, the peak yield in crop 2 may remain approximately the same for different treatments with a sharp drop in crop 3 in one of the combinations, although a high yield is maintained in the other. The high chloride additions show the drop in crop 3 the most frequently. Sharp drops in yields are least prevalent in the case of the sodium sulfate treatments.

THREE-SALT TREATMENTS

In the three-salt combinations (table 5), an attempt has been made to group the treatments so that two salts remain constant while the third is variable.

Treatment 61, with a concentration of 0.2 per cent sodium carbonate, 0.1 per cent sodium chloride and 0.2 per cent sodium sulfate, has been used as the basis for comparison. In this combination we find the additive effects of all components apparent in crop 1. In crop 2 there is the usual stimulation followed by a well-sustained growth in crops 3 and 4.

In treatments 61, 63, 65 and 67, the sodium sulfate and the sodium chloride additions remain constant while the sodium carbonate is consistently increased. The effect of this variation is increased toxicity to the first crop, the amount of toxicity increasing in the order of the magnitude of the treatment. The second crop shows a stimulation for the 0.4 per cent sodium carbonate addition over the 0.2 per cent. The 0.8 per cent addition proved too high a concentration for crop growth. The third and fourth crops show a decided stimulation for the 0.4 per cent sodium carbonate addition over the 0.2 per cent, while the 0.6 per cent addition in the fourth crop results in an abnormally high yield.

The effect of increasing the chlorides while the carbonate and the sulfate additions remain constant is shown in treatments 61, 73 and 75. The results show a beneficial effect in all crops by increasing chlorides from 0.1 per cent to 0.4 per cent in the presence of 0.2 per cent each of sodium sulfate and sodium carbonate. In the third and fourth crops 0.6 per cent sodium chloride is toxic.

TABLE 5

Soil treatments, salt recovery and crop yield

Three-salt combinations

NUMBER	TREATMENT			FIRST CROP					SECOND CROP					THIRD CROP					FOURTH CROP				
	Na_2CO_3 per cent	NaCl per cent	Na_2SO_4 per cent	Yield per cent	Na_2CO_3 per cent	Total Na_2CO_3 per cent	NaCl per cent	Na_2SO_4 per cent	Yield per cent	Na_2CO_3 per cent	Total Na_2CO_3 per cent	NaCl per cent	Na_2SO_4 per cent	Yield per cent	Na_2CO_3 per cent	Total Na_2CO_3 per cent	NaCl per cent	Na_2SO_4 per cent	Yield per cent	Na_2CO_3 per cent	Total Na_2CO_3 per cent	NaCl per cent	Na_2SO_4 per cent
61	0.2	0.1	0.2	61.9	0.031	0.093	0.093	0.169	127.7	0.053	0.081	0.056	0.170	120.0	0.033	0.093	0.062	0.174	87.6	0.037	0.082	0.060	0.181
63	0.4	0.1	0.2	49.7	0.064	0.149	0.080	0.186	159.5	0.111	0.144	0.055	0.137	148.6	0.073	0.141	0.082	0.206	114.8	0.084	0.135	0.078	0.348
65	0.6	0.1	0.2	44.7	0.103	0.205	0.073	0.152	117.7	0.166	0.194	0.124	0.147	106.6	0.110	0.196	0.063	0.122	216.6	0.152	0.093	0.053	0.213
67	0.8	0.1	0.2	10.5	0.164	0.294	0.094	0.169	0.00	0.222	0.234	0.101	0.177	4.6	0.161	0.232	0.098	0.201					
69	0.2	0.1	0.4	54.5	0.010	0.083	0.098	0.386	148.6	0.036	0.071	0.089	0.246	141.0	0.019	0.069	0.073	0.376	121.3	0.020	0.056	0.060	0.336
71	0.2	0.1	0.8	66.7	0.015	0.072	0.073	0.764	110.6	0.018	0.050	0.066	0.676	84.1	0.010	0.062	0.072	0.720	159.7	0.013	0.048	0.064	0.650
73	0.2	0.4	0.2	71.7	0.010	0.073	0.325	0.193	137.7	0.029	0.058	0.305	0.153	118.9	0.013	0.062	0.371	0.180	111.3	0.024	0.059	0.303	0.175
75	0.2	0.6	0.2	67.6	0.010	0.074	0.470	0.217	139.1	0.024	0.053	0.401	0.152	30.1	0.019	0.061	0.393	0.159	75.1	0.016	0.051	0.166	0.166
77	0.4	0.2	0.2	58.2	0.074	0.153	0.092	0.144	166.5	0.104	0.126	0.130	0.132	119.5	0.080	0.122	0.110	0.139	133.5	0.072	0.115	0.106	0.126
81	0.4	0.4	0.2	67.0	0.050	0.138	0.182	0.152	201.6	0.087	0.123	0.215	0.128	128.9	0.040	0.121	0.244	0.117	114.7	0.072	0.118	0.199	0.113
79	0.2	0.2	0.6	68.3	0.015	0.076	0.106	0.414	122.2	0.042	0.071	0.135	0.444	139.9	0.013	0.069	0.156	0.544	92.0	0.017	0.047	0.166	0.550
83	0.2	0.4	0.4	54.8	0.024	0.091	0.153	0.310	156.5	0.023	0.059	0.268	0.300	113.8	0.022	0.078	0.297	0.360	96.8	0.014	0.055	0.215	0.326
85	0.4	0.1	0.4	76.2	0.054	0.133	0.070	0.308	150.4	0.078	0.122	0.055	0.263	127.0	0.102	0.152	0.059	0.257	96.2	0.073	0.121	0.045	0.185

In each of the three groups just discussed, it appears that the increase in one component to a concentration of 0.4 per cent increases the stimulation in crop 2 noticeably and maintains it for the average of the two succeeding crops. In crop 1 the stimulation is marked only in the case of 0.4 per cent sodium chloride and is slight with the 0.6 per cent addition.

Lipman and Gericke (3) called attention to a protective influence of certain salts against each other when barley was grown on clay adobe soil to which alkali salts were added. They found that certain salt combinations produce greater yields of barley when in combination with lower additions of the single-salt applications. These mixtures of salt, even under higher osmotic pressure, produced greater yields than either salt when added singly. They called this "antagonism of anions." The combinations of salts used in this experiment were not planned primarily for a study of antagonism of anions; hence combinations of salts involved are not always comparable. It may be of interest when all data on all crops are presented to scan treatments closely to ascertain what indications of antagonism of anions exist.

The authors wish to call attention to a persistent toxicity in the first crop and in general a stimulation in the second crop. This is in direct contradiction to the effect observed by Lipman and Gericke (3) when two crops of barley were grown on clay adobe soil to which various alkali salt concentrations were added. Much of this contradiction should be attributed to the different type of soil used, a discussion of which is reserved for a later paper.

Mixtures of salts which are very toxic in the first crop may produce an abundant stimulation in the second crop. The authors do not wish to interpret this influence as due to antagonism of anions. Neither are they ready to offer any definite explanation for this action other than to suggest a few possibilities; namely, a readjustment of the bases in the soil solution caused by the addition of soluble salts; a possible improvement in the soil structure and physical condition; increase of plant-foods brought about by a disturbed equilibrium of bases in the soil; and a possible increase in fertility due to the effect on certain soils of stimulating ammonification and nitrification as shown by data on the effect of alkali salts on bacterial activities of soils (1).

SALT RECOVERIES

For convenience in our discussion, all treatments have been referred to in the terms of the amount of salts added. In this usage the reader must not lose sight of the fact that the recoverable salts constitute the better indication of the salt involved in influencing crop growth. The recoveries vary rather widely as noted in previous articles, but in general, the recovery of the first crop, based on the addition, is about 30 per cent for sodium carbonate, 75 per cent for sodium chloride, and 80 per cent for sodium sulfate. Some leaching of salts took place in the pots used, especially toward the end of the experiment. The sulfates in particular attacked and penetrated the glazed surface of the jars used.

The critical concentration is not the same in each crop. Where four crops are grown, a stimulation far above normal, especially in crop 2, and a normal growth in concentrations too toxic for growth in crop 1 are often found. Again in crop 4 the soil seems to have recovered from the toxic influence to the extent that a fair growth is possible. This increased production is not entirely a function of the decreased salt recovery, but also a result of soil adjustments to this salt content, which tends to permit crop growth approaching normal.

For the sulfate concentrations used in this group, only the 2.4 per cent addition with a recovery of 2.16 per cent shows that the critical concentration has been exceeded while 1.5 per cent shows some decrease in crop 1. When used together with additions of other salts, much smaller amounts of sodium sulfate may be decidedly toxic.

Sodium carbonate shows definite toxicity with a recovery concentration of 0.176 per cent and produces practically no crop at 0.314 per cent. A recovery of 0.2 per cent is usually a little beyond the critical concentration, whether alone or in combinations.

Chloride additions of 0.4 per cent giving a recovery of 0.298 show definite toxicity, although the critical concentration has been reached at approximately 0.561 per cent recovery. In the two- or three-salt additions, each salt maintains its characteristic critical concentration, which may be slightly modified by the effect of the other components. When near the critical concentration of any salt, additional salts are always disastrous to crop growth, whether it be the same salt or one of the others.

GERMINATION AND GRAIN YIELD

Table 6 contains the average grain yields for the second and fourth crops expressed in per cent of the checks, considering the average yield of check soil as 100 per cent. Average germination data are given for the first, third and fourth crops, expressed in per cent of the check soil.

Grain yields were not available for crop 1, as it was not grown to maturity. Crop 3 began to ripen during the rainy season and as a result of the unfavorable climatic conditions, very little filling of the heads took place.

An inspection of the table shows much variation in grain yields in the second and fourth crops. In general it may be said that single-salt treatments reduce grain production more than double or triple treatments. This is accounted for by the fact that in many double- and triple-salt treatments very little stooling occurred. The plants were growing under a handicap of high osmotic pressures which were not favorable to a development of abundant foliage and stalks. The plants, therefore, developed only a few heads but these in turn were usually well filled. In all the tolerance studies, it has been noted that carbonates added singly in low concentrations tend to produce broad leaves and luxuriant growth of plants, but do not produce well filled heads. The reason is probably due to the fact that carbonates are stimulating to

TABLE 6

Germination and grain yield expressed as per cent of the check

NUMBER	GERMINATION			GRAIN	
	First crop	Second crop	Third crop	Second crop	Fourth crop
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
1	100	100	100	100.0	100.0
3	91	115		88.5	
5	100	52	100	56.8	90.2
7	87	86	90	0	25.7
9	78	67		0	
11	105	115		54.6	
13	96	82	84	120.5	85.1
15	64	9		11.4	
17	105	106		100.0	
19	96	92	105	95.5	83.2
21	96	100	105	31.8	89.4
23	105	105		88.5	
25	92	86	116	66.0	64.0
89	00	00		0	
27	100	85	120	143.0	112.5
29	110	110	105	0	232.5
31	82	86	55	95.5	96.6
33	91	33		43.1	
35	68	33		43.1	
37	91	95	100	111.0	82.7
39	82	105	95	72.9	117.5
41	68	100	90	79.4	89.5
43	59	62		136.4	
45	64	53		38.6	
47	101	110	111	86.5	69.0
49	91	110	111	88.5	66.5
51	96	105	111	95.5	83.3
53	110	105	116	109.0	75.1
55	105	95	120	0	2.1
57	64	57		0	
59	64	86		0	
61	96	95	106	127.4	82.5
63	91	106	116	189.5	122.7
65	82	110	100	166.0	203.5
67	105	95		0	
69	101	106	100	125.0	129.4
71	105	106	111	77.1	166.5
73	105	106	95	152.4	115.7
75	110	76	65	77.1	71.5
77	105	115	111	207.0	135.8
79	110	110	105	109.0	93.3
81	110	115	120	293.0	105.4
83	105	110	90	521.0	103.3
85	101	100	111	305.0	94.4

ammonification and nitrification in the soil, and under favorable conditions the plant begins growth with an abundant supply of nitrates which results in a stimulation of the initial growth and produces a bushy broad leaved plant. Available nitrogen not being present in sufficient amount in the soil to maintain the same rate of growth of the plant as during the early period causes a reduced yield of grain because of depletion of nitrogen in the soil during the later period of its growth cycle. The need of sufficient available nitrogen in the soil to supply the plant at the time of heading and filling is important for high grain production, as shown by previous work at this station (8). The three-salt mixtures are favorable to grain production over single-salt treatments because they are depressing to the growth of the plant during the initial stages of growth.

Sodium chloride treatments seem to retard stooling of plants and to produce spindly stalks. This results in plants that usually produce more grain in proportion to straw. Single treatments of sodium sulfate do not seem to show any particular characteristics in either direction.

Sodium chloride additions produce the greatest reduction in germination of barley. Carbonates and sulfates in low concentrations show very little effect and only the highest carbonate and sulfate treatments affected germination.

The three-salt treatments give fairly high germination even if the total salt content is high. This is evident in all three-salt treatments, except where the sodium chloride addition is high. Sodium chloride seems to be the determining factor in reducing germination wherever it appears in the combinations.

There is a gradual reduction in germination in each succeeding crop both in soils with added salts and in the control soils, as shown by the fact that the actual germination in the checks for the three crops is 91, 87 and 83 per cent of the seeds planted. This reduction in germination is not present in the three-salt combinations, where the germination continues to be higher than the checks.

SUMMARY

1. Four crops of barley were grown on Idaho soil treated with various concentrations of the single alkali salts together with various combinations of these salts. The salts used were sodium carbonate, sodium chloride and sodium sulfate.

2. Toxicities of the salt applications varied with the successive crops. In general, regardless of the type of treatment, additions of salts were most toxic to the first crop.

3. The majority of salt treatments produced a stimulation in yield of barley in the second crop.

4. The third crop yields showed in general toxic effects.

5. The yields in the fourth crop of barley showed a tendency of the soils to produce yields approaching normal.

6. The three-salt combinations, the concentration of which gives a soil

solution with a higher osmotic pressure than some of the single-salt treatments, were usually stimulating to the second, third and fourth crops. Three-salt mixtures were decidedly toxic to the first crop of barley.

7. Sodium chloride, when present in a combination that did not exceed the toxic limit for barley, produced the greatest stimulation in the second crop.

8. Sodium sulfate, once it showed toxicity, did not become much more acute, even with further additions, until very high concentrations were reached.

9. Certain alkali salt treatments in Idaho soil resulted in yields of barley which are in direct contradiction to those obtained by Lipman and Gericke when California clay adobe soil was treated with similar salts and barley was grown thereon. This finding further emphasizes the fact that tolerance studies on artificially prepared alkali soils should be interpreted in the light of tolerance of soil for alkali salts rather than tolerance of crops for these salts, since different soils show widely divergent action toward alkali. The above conclusions obviously are drawn from a study of soils artificially impregnated with alkali.

10. Discussion of chemical considerations in the stimulation observed in the second crop are deferred till the data for all crops have been presented.

REFERENCES

(1) Gibbs, William M., Bachelor, H. W., and Magnuson, H. P. 1925 The effects of alkali salts on bacteriological activities of soil: I. Ammonification, II. Nitrification, III. Ammonification, nitrification and crop yield. *In* Soil Sci., v. 19, p. 333–379.

(2) Headley, F. B., Curtis, E. W., and Scofield, C. S. 1916 Effect of sodium salts in the soil. *In* Jour. Agr. Res., v. 6, p. 856–869.

(3) Lipman, Charles B., and Gericke, W. F. 1915 Antagonism between anions as affecting barley yields on clay-adobe soil. *In* Jour. Agr. Res., v. 4, p. 201–218.

(4) Lipman, Charles B., and Gericke, W. F. 1919 The inhibition by stable manure of injurious effects of alkali salts in soils. *In* Soil Sci., v. 7, p. 105–120.

(5) Neidig, Ray E., and Magnuson, H. P. 1923 Equilibrium studies of sodium carbonates and bicarbonates in some Idaho soils. *In* Soil Sci., v. 14, p. 295–320.

(6) Neidig, Ray E., and Magnuson, H. P. 1924 Alkali Studies: I. Tolerance of wheat for alkali in Idaho soils. *In* Soil Sci., v. 18, p. 449–467.

(7) Neidig, Ray E., and Magnuson, H. P. 1925 Alkali Studies: II. Tolerance of alfalfa, corn and sweet clover for alkali in Idaho soils. *In* Soil Sci., v. 19, p. 115–124.

(8) Neidig, Ray E., and Snyder, Robert S. 1922 The effect of available nitrogen on the protein content and yield of wheat. Idaho Agr. Exp. Sta. Res. Bul. 1.

PLATES

PLATE 1

SECOND CROP OF BARLEY GROWN ON ALKALI TREATED SOIL

The numbers on the pots correspond to the numbers of treatments shown in the tables in the text, even numbers being the duplicate of the odd number just preceding.

FIG. 1. Representative single-salt treatments.

2—check	16—0.8 per cent NaCl
6—0.4 per cent Na_2CO_3	18—0.2 per cent Na_2SO_4
8—0.6 per cent Na_2CO_3	25—1.5 per cent Na_2SO_4
12—0.2 per cent NaCl	90—2.4 per cent Na_2SO_4

FIG. 2. Representative two-salt treatments.

2—check
27—0.4 per cent Na_2CO_3 plus 0.1 per cent NaCl
33—0.2 per cent Na_2CO_3 plus 0.6 per cent NaCl
36—0.6 per cent Na_2CO_3 plus 0.6 per cent NaCl
41—0.3 per cent NaCl plus 0.2 per cent Na_2SO_4
43—0.6 per cent NaCl plus 0.2 per cent Na_2SO_4
45—0.6 per cent NaCl plus 0.6 per cent Na_2SO_4

FIG. 3. Representative three-salt treatments.

2—check
65—0.6 per cent Na_2CO_3 plus 0.1 per cent NaCl plus 0.2 per cent Na_2SO_4
72—0.2 per cent $N_{12}CO_3$ plus 0.1 per cent NaCl plus 0.8 per cent Na_2SO_4
76—0.2 per cent Na_2CO_3 plus 0.6 per cent NaCl plus 0.2 per cent Na_2SO_4
81—0.4 per cent Na_2CO_3 plus 0.4 per cent NaCl plus 0.2 per cent Na_2SO_4
83—0.2 per cent Na_2CO_3 plus 0.4 per cent NaCl plus 0.4 per cent Na_2SO_4
85—0.4 per cent Na_2CO_3 plus 0.1 per cent NaCl plus 0.4 per cent Na_2SO_4

Fig. 1

Fig. 2

Fig. 3

PLATE 2

The numbers on the pots correspond to the numbers of treatments shown in the tables in the text, even numbers being duplicates of the odd numbers just preceding.

FIG. 1. Representative single-salt treatments.

2—check
6—0.4 per cent Na_2CO_3
7—0.6 per cent Na_2CO_3
12—0.2 per cent NaCl
14—0.4 per cent NaCl

15—0.8 per cent NaCl
18—0.2 per cent Na_2SO_4
25—1.5 per cent Na_2SO_4
90—2.4 per cent Na_2SO_4

FIG. 2. Representative two-salt treatments.

2—check
27—0.4 per cent Na_2CO_3 plus 0.1 per cent NaCl
33—0.2 per cent Na_2CO_3 plus 0.6 per cent NaCl
36—0.6 per cent Na_2CO_3 plus 0.6 per cent NaCl
41—0.3 per cent NaCl plus 0.2 per cent Na_2SO_4
43—0.6 per cent NaCl plus 0.2 per cent Na_2SO_4
45—0.6 per cent NaCl plus 0.6 per cent Na_2SO_4

FIG. 3. Representative three-salt treatments.

2—check
65—0.6 per cent Na_2CO_3 plus 0.1 per cent NaCl plus 0.2 per cent Na_2SO_4
72—0.2 per cent Na_2CO_3 plus 0.1 per cent NaCl plus 0.8 per cent Na_2SO_4
76—0.2 per cent Na_2CO_3 plus 0.6 per cent NaCl plus 0.2 per cent Na_2SO_4
81—0.4 per cent Na_2CO_3 plus 0.4 per cent NaCl plus 0.2 per cent Na_2SO_4
83—0.2 per cent Na_2CO_3 plus 0.4 per cent NaCl plus 0.4 per cent Na_2SO_4
85—0.4 per cent Na_2CO_3 plus 0.1 per cent NaCl plus 0.4 per cent Na_2SO_4

FIG. 1

FIG. 2

FIG. 3

FOURTH CROP OF BARLEY GROWN ON ALKALI TREATED SOIL

The numbers on the pots correspond to the numbers of treatments shown in the tables in the text, even numbers being the duplicate of the odd number just preceding.

FIG. 1. Representative single-salt treatments.

2—check

6—0.4 per cent Na_2CO_3

7—0.6 per cent Na_2CO_3

14—0.4 per cent NaCl

25—1.5 per cent Na_2SO_4

FIG. 2. Representative two- and three-salt treatments.

2—check

27—0.4 per cent Na_2CO_3 plus 0.1 per cent NaCl

41—0.3 per cent NaCl plus 0.2 per cent Na_2SO_3

65—0.6 per cent Na_2CO_3 plus 0.1 per cent NaCl plus 0.2 per cent Na_2SO_4

72—0.2 per cent Na_2CO_3 plus 0.1 per cent NaCl plus 0.8 per cent Na_2SO_4

76—0.2 per cent Na_2CO_3 plus 0.6 per cent NaCl plus 0.2 per cent Na_2SO_4

81—0.4 per cent Na_2CO_3 plus 0.4 per cent NaCl plus 0.2 per cent Na_2SO_4

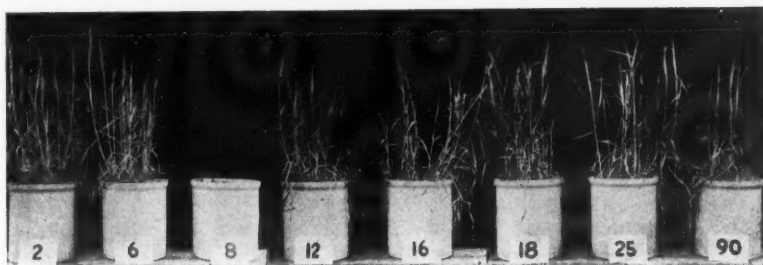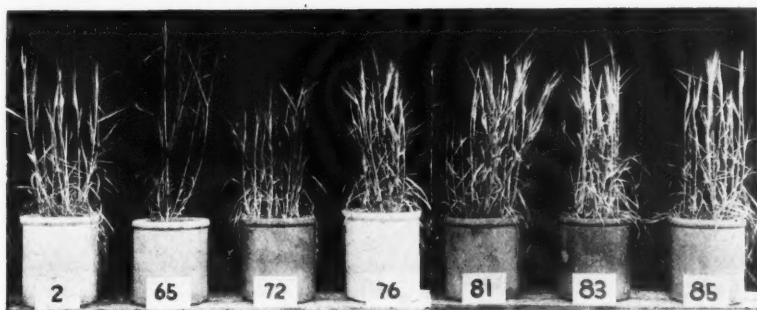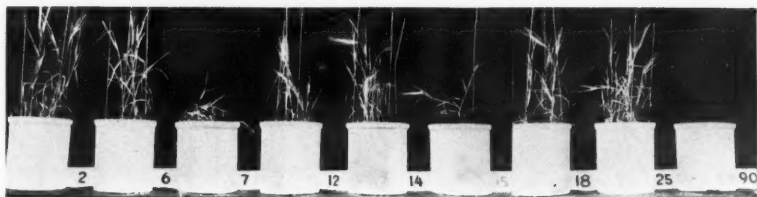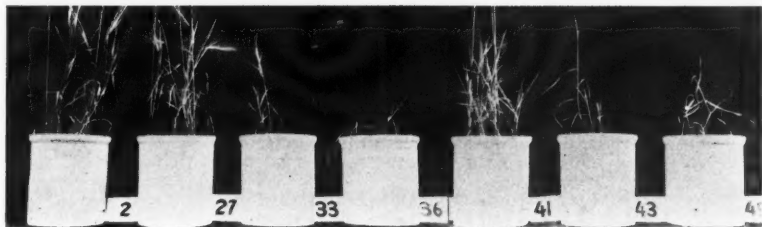83—0.2 per cent Na_2CO_3 plus 0.4 per cent NaCl plus 0.4 per cent Na_2SO_4

390

FIG. 1

FIG. 2

THE ACETONE METHOD OF EXTRACTING SULFUR FROM SOIL

R. H. SIMON AND C. J. SCHOLLENBERGER

Ohio Agricultural Experiment Station

For several years there has been an interest in the use of sulfur as a treatment for soils, on many types of which elemental sulfur has been applied alone or in combination with common fertilizing elements. The response of some soils to applied sulfur has been attributed to its absence from the natural soil or to the fact that it is a limiting factor for plant growth.

Sulfur incorporated with the soil is eventually changed to sulfates, for most soils have a capacity for oxidation commonly known as the "sulfofying power."

The usual procedure for estimating the oxidation of sulfur in the soil is to determine the total soluble sulfates. This method is objectionable in that it may not correctly distinguish the sulfates from the oxidized elemental sulfur recently incorporated with the soil; the total sulfates may include those contributed by the oxidation of organic sources of sulfur with those occurring naturally in the soil; thus such a condition requires as a check, the determination of the latter.

The method of extracting a soil with water by the usual 1:5 dilution disturbs the whole system, for the conditions of extraction are widely different from those of oxidation. A representative determination can be made, however, from the water extract, provided it can be filtered free from colloidal material. A clear filtrate may be obtained by taking the soil-water system from the shaking machine and filtering it through a dry folded filter with the soil as a filtering medium.

Not only would the complete removal of sulfates by repeated leachings be a long process, but because of the changing equilibrium, as well as the modified biological conditions within the soil, it is questionable whether these combined leachings would actually represent the soluble sulfates for that period of oxidation.

Both methods of extraction with water may give relative amounts of sulfates where several soils are compared for their "sulfofying power," but there is no check on the sulfates from other sources, except by difference.

The determination of the oxidized elemental sulfur which can be made more directly by the use of a solvent that would efficiently recover the unoxidized sulfur, would eliminate the objections to the processes of extraction by water. The most promising solvent adapted to the necessary conditions of extraction

393

is acetone, a substance which has a high solubility for sulfur, a low boiling point, purity, and adaptation to an apparatus that would extract a sufficient quantity of soil for an accurate determination of sulfur with a minimum of solvent.

APPARATUS

The apparatus used for the recovery of sulfur in this work is a slightly modified "Underwriters Apparatus" (2). The important change is the replacement of the siphon tube and paper thimble by a glass thimble supported in the same way. This glass thimble is 100 mm. in length and 25 mm. in diameter, with a drain at the bottom, 10 mm. in diameter, fitted over with a perforated porcelain disc 20 mm. in diameter. A compact felt of asbestos supports the charge of soil. The described substitution makes the apparatus easier to clean and gives a complete extraction. Should it be necessary to make a new felt for each determination, it must be thoroughly dried before it is used.

METHOD

The method of extracting sulfur from soils is a modification of the method for free sulfur reported by J. W. W. Dyer (1).

A charge of 20 gm. of dried soil passing through a 0.5-mm. sieve is placed in the thimble and sufficiently settled to allow the acetone to percolate slowly through the column instead of channeling through the soil. In the flask 50 cc. of acetone is placed and kept at a low temperature of about 56°C. Sufficient heat is maintained to keep the acetone condensate percolating throug the soil with about 2 to 3 cm. pressure for 3 to 4 hours. This time is sufficient for heavy soils; for others less time is required.

The acetone containing the dissolved sulfur is slowly distilled and recovered. The sulfur residue may be evaporated to constant weight and a direct determination made for some soils. (A gummy residue of questionable purity from the two soil-types used, however, prevented this practice.)

The extracted sulfur dissolved in a few cubic centimeters of acetone, is oxidized directly in the flask by the addition of quantities of 0.5 to 1 gm. of powdered potassium permanganate. The solution is thoroughly mixed and allowed to stand at room temperature for 1 hour. If the purple color disappears more permanganate must be added.

The oxidized residue is redissolved in 5 cc. of concentrated HCl (specific gravity 1.16) for each gram of permanganate used. The flask is covered and the excess acid evaporated on a steam plate. The residue is taken up with a few drops of HCl and diluted to 100 cc., filtered if necessary, and the sulfur precipitated at boiling temperature with 3 cc. of a 10 per cent barium chloride solution. The usual method for sulfates completes the determination.

DATA AND DISCUSSION

Almost the entire theoretical amount of barium sulfate was obtained by dissolving 0.05 gm. of sulfur in 50 cc. of acetone and following the method as

outlined.   Flowers of sulfur were used in this work in order to have the conditions similar to those in other work in progress.

The data of average duplicate determinations are recorded in table 1.

Estimated mixtures of sulfur with two different soil types were extracted for 4 hours: the results show that the extraction was complete.   Further extraction with acetone recovered a very slight amount of sulfur.   Calcium sulfate added to the extracted soil and the process continued for another period failed to contribute an appreciable amount of sulfates in the extract.   These results show that the acetone does not extract sulfate from the soil, rendering the results high.

TABLE 1

Barium sulfate obtained by the acetone method

SULFUR	SOIL	ACETONE	TIME	SULFUR AS $BaSO_4$
gm.		*cc.*	*hours*	*gm.*
0.05		50	4	0.3514
0.05	Wooster	50	4	0.3540
0.05	Basic clay	50	4	0.3497
——*	Wooster	50	4	0.0006
——*	Basic clay	50	4	0.0012
$CaSO_4 \cdot 2H_2O$†	Basic clay	50	4	Trace

* Additional extraction of the two previous charges for 4 hours each.

† Addition of $CaSO_4 \cdot 2H_2O$ to the extracted basic clay and again extracted for 4 hours.

TABLE 2

Sulfur recovered after 4- and 8-week periods of incubation

TIME	SULFUR RECOVERED (UNOXIDIZED)	SULFATES OXIDIZED
weeks	*per cent*	*per cent*
4	18.8	81.1
8	12.3	86.8

Further recovery of sulfur by extraction was made in an incubated soil-sulfur mixture in which the sulfur was oxidized under controlled conditions of moisture and temperature.   The basic clay soil received 0.2 gm. of flowers of sulfur per 300 gm. of soil and was incubated at 50 per cent of the moisture-holding capacity for the two periods (table 2).

From the percentages in the first column in table 2 the amount of sulfur oxidized can be calculated.   The percentage of oxidized sulfur in the second column, determined as soluble sulfates, is checked by the acetone-soluble sulfur, hence only the first extraction by acetone is necessary to control the oxidation process.

From the decrease in elemental sulfur from one period to the next the rate of oxidation may be calculated.

CONCLUSIONS

The small charges of soil give measurable results for determining the oxidation of elemental sulfur.   The residual sulfates, which are produced in the soil by the oxidation of organic sulfur and are carried into the soil-sulfur mixture, are not affected by the solvent, hence a condition of error is eliminated.

By determining the amount of the remaining elemental sulfur, a positive measure of the quantity and rate of oxidation is obtained during the entire period of incubation or field practice.

The loss of sulfur as H_2S is eliminated as a source of error.

A battery of extractions may be operated on a single hot plate requiring little attention.

Acetone is a reliable solvent for extracting sulfur from soils where the proportion of applied sulfur is within its solubility.

REFERENCES

(1) DYER, J. W. W.   1922   Sulfur in vulcanized rubber.   *In* Jour. Soc. Chem. Indus., v. 41, p. 251.
(2) Report of Rubber Insulation Committee.   1917   *In* Jour. Indus. Engin. Chem. v. 9, p. 314.

COMPARATIVE STUDY OF THE "SIX TYPES" OF NUTRIENT SOLUTIONS IN RELATION TO THE GROWTH OF POTATO PLANTS IN SAND CULTURES

EARL S. JOHNSTON

Maryland Agricultural Experiment Station

A scheme for studying nutrient solutions made up from various combinations of the six essential ions (exclusive of iron) has been suggested by Livingston and Tottingham (4). These various salt combinations are referred to by Livingston (3) as types and are designated as follows:

TYPE I	TYPE II	TYPE III	TYPE IV	TYPE V	TYPE VI
$Ca(NO_3)_2$	$Ca(NO_3)_2$	$Ca(H_2PO_4)_2$	$Ca(H_2PO_4)_2$	$CaSO_4$	$CaSO_4$
KH_2PO_4	K_2SO_4	KNO_3	K_2SO_4	KNO_3	KH_2PO_4
$MgSO_4$	$Mg(H_2PO_4)_2$	$MgSO_4$	$Mg(NO_3)_2$	$Mg(H_2PO_4)_2$	$Mg(NO_3)_2$

The author (1, 2) employed these solutions in a study of the growth of potato plants in sand cultures, but was unable to determine the relative values of these various types because each was studied under a different set of environmental conditions, the work having extended over several years. It was found that the best growth usually occurred in cultures having high atomic proportions of nitrogen. Variations in the atomic proportions of elements associated with the best seven cultures in the six types were as follows: nitrogen, 4 to 6; phosphorus, 2 to 4; potassium, 2 to 4; sulfur, 1 to 2; calcium, 3 to 1; and magnesium, 2 to 1. These atomic proportions refer only to each solution of the above types having an initial total osmotic concentration of approximately one atmosphere and consisting of all possible combinations of the three salts in which the increments of change are equal to one-eighth of their total molecular concentration.

In the present work, three of the best solutions of each type were selected for the purpose of making a comparative study. Each culture consisted of 3 Irish Cobbler potato sprouts planted in a 2-gallon glazed earthenware jar containing 9000 gm. of air-dry white quartz sand. At the beginning of each experiment and at the time of each solution renewal, the moisture content was 15 per cent of the dry weight of the sand. A wax seal prevented the loss of water by evaporation. The method of conducting these experiments was similar to that previously described (2). Data in this study were obtained from four series of experiments, two conducted in the winter and spring of

397

1924 and two in 1925. The solutions selected for each of these four series of experiments are indicated in table 1. The solutions selected for types II and VI of series B, C and D were somewhat different from those of series A because it was found that these types were slightly better represented by the later selection.

In series A and C the plants were grown for 6 weeks in the culture jars and then harvested, whereas the growth periods for series B and D were 4, and 4½ weeks respectively. Solutions were renewed weekly in series A and B and semi-weekly in series C and D. When transpiration rates were high it was found necessary to add distilled water between dates of solution renewal, in order to maintain the moisture content of the sand at approximately its original value. Temperature and atmospheric moisture records as well as measurements of plant height and transpiration were kept. In this paper consideration is given to the dry weight of the plants and to the nature of the solutions used. Table 2 shows the dry weights of the plants (tops and roots) per culture, expressed in terms relative to the average (considered as

TABLE 1

Solutions used in the four series for the simultaneous comparison of the six types of nutrient solutions

	TYPE I	TYPE II	TYPE III	TYPE IV	TYPE V	TYPE VI
Series A...............	R_2S_4	R_1S_5	R_4S_1	R_1S_4	R_3S_4	R_1S_5
	R_3S_3	R_3S_4	R_4S_1	R_2S_1	R_4S_3	R_3S_3
	R_3S_4	R_2S_5	R_4S_2	R_2S_2	R_6S_1	R_4S_2
Series B, C, D..........	R_2S_4	R_1S_5	R_4S_1	R_1S_4	R_3S_4	R_1S_3
	R_3S_3	R_4S_3	R_6S_1	R_2S_1	R_4S_3	R_1S_5
	R_3S_4	R_2S_5	R_6S_2	R_2S_2	R_6S_1	R_6S_1

unity) of each series. The average relative dry weight corresponding to each type is also indicated in the table.

Table 2 shows values of unity or above for most of the cultures of the four series treated with solutions of types I and II. With a few exceptions, all the other cultures, that is, those treated with solutions of the four remaining types, show values less than unity. Such a brief survey seems to indicate the superiority of types I and II over the other types. It is not safe, however, to draw conclusions from such a superficial survey, since each culture of each series contained but 3 plants and a glance through the values of any one culture for the different series will reveal considerable variation. In order to arrive at an approximate value for each solution type all the cultures of that type were averaged together; thus, each type of solution is represented by the average dry weight values of 36 plants. It is believed that this number of plants will at least indicate the approximate values of the six solution types.

The average values clearly show the superiority of types I and II over the others. Types IV and VI appear to be of least value. These six average

values seem to fall naturally into the following three groups; I and II, III and V, and IV and VI. This peculiarity appears to be related to the manner in which the NO_3 radical is united with Ca, K, and Mg. A reference to the chemicals making up the six types shows that nitrate occurs as $Ca(NO_3)_2$ in types I and II, as KNO_3 in types III and V, and as $Mg(NO_3)_2$ in types IV and VI. In these combinations $Ca(NO_3)_2$ appears to be the best carrier of nitrogen, and KNO_3 to be somewhat better than $Mg(NO_3)_2$. Here, as reported in previous work, it seems probable that high concentrations of $Mg(NO_3)_2$

TABLE 2

Dry weight of tops and roots for each culture, expressed in terms relative to the average of each series

SOLUTION TYPE	CULTURE NUMBER	SERIES A	SERIES B	SERIES C	SERIES D	AVERAGE
	Average	1.00 (2.9 gm.)	1.00 (3.1 gm.)	1.00 (5.7 gm.)	1.00 (6.3 gm.)	
I	1	1.17	1.74	1.49	1.10	1.23
	2	1.17	1.48	0.89	1.19	
	3	1.03	1.16	0.98	1.30	
II	4	1.17	1.13	1.47	1.33	1.18
	5	1.28	1.26	0.97	1.16	
	6	1.21	1.10	1.09	1.03	
III	7	0.93	0.87	0.95	0.87	0.92
	8	0.79	0.81	0.93	0.92	
	9	0.97	0.87	1.23	0.94	
IV	10	0.86	0.71	0.95	0.92	0.84
	11	0.83	0.55	0.88	0.84	
	12	0.97	0.84	0.84	0.92	
V	13	1.00	1.06	0.74	0.89	0.95
	14	1.14	0.90	0.98	1.03	
	15	0.72	0.84	1.16	0.89	
VI	16	1.00	0.68	0.74	0.92	0.88
	17	0.86	1.23	0.95	0.89	
	18	0.83	0.97	0.72	0.79	

are toxic, the beneficial effects of nitrogen being nullified by the ill effects of magnesium.

In order to compare the plant values with the atomic proportions of the various elements found in the six solution types, table 3 was constructed. The atomic proportions represent average values of the elements occurring in the four series. The method of determining atomic proportions was similar to that described in a previous report (2).

Table 3 shows high nitrogen values for types I, II and IV. The highest plant values occur for types I and II, whereas that of IV is the lowest. On the other hand the highest magnesium value occurs for type IV which, it is be-

lieved, accounts for the low plant value of 0.84. The next lowest plant value occurs for type VI, which has three atomic proportions of magnesium, one less than type IV but more than any of the other types. It has the same atomic proportion of nitrogen as type III, but a lower dry weight index. The ratio values of N to Mg for the six types are as follows:

I	II	III	IV	V	VI
3.5	4.5	2.5	2.0	4.0	1.6

The two lowest plant values occur where this ratio is lowest, but the highest plant values, those of types I and II, are not in the same order as their ratio values. The low plant value for type V with its high N − Mg ratio may be partly explained by the low atomic proportion of nitrogen, which is 4 as compared with 7 and 9 in types I and II, respectively. It is likewise rather difficult to see why type I should be better than type II, which has more nitrogen. It should be remembered, however, that the other elements play important rôles in plant growth and that they are to be considered even though

TABLE 3

Average atomic proportions of elements used in the cultures representing each type in the four series, together with the average relative dry weights per culture for each type

SOLUTION TYPE	N	P	K	S	Ca	Mg	AVERAGE RELATIVE DRY WEIGHTS
I	7	3	3	2	2	2	1.23
II	9	4	3	2	4	2	1.18
III	5	3	5	2	1	2	0.92
IV	8	5	3	2	2	4	0.84
V	4	2	4	3	3	1	0.95
VI	5	2	2	3	3	3	0.88

the relationship is not obvious. It is possible there may be an acidity relationship, although McCall and Haag (5) state, "The variations in plant growth, within any one type of solution cannot be correlated with differences in the hydrogen-ion concentrations of the solutions." Although this may be true within a given type their figures show a greater variation between certain types than between individual solutions within a given type. Solution types containing KH_2PO_4 are less acid than the other types. Their figures averaged for each type give the following pH values:

I	II	III	IV	V	VI
4.6	3.7	3.7	3.8	3.7	4.9

A difference of 0.9 pH is found between type I and type II. The averages of the pH values corresponding to the solutions used in this investigation show approximately this same difference in acidity. The greater acidity of type II solutions may account for its dry weight index being less than that of type I in spite of its higher nitrogen content.

SUMMARY

It appears from the data presented in these studies that solutions of types I and II are better suited for salt nutrition studies with the Irish Cobbler potato plant than any of the four other types in which the dry weight of the plants is used as the growth criterion. Best growth is associated with high nitrogen content of the nutrient solutions except where the nitrate radical is supplied as a salt of magnesium. Of the three salts carrying nitrogen, $Ca(NO_3)_2$ was superior to either KNO_3 or $Mg(NO_3)_2$.

REFERENCES

(1) JOHNSTON, EARL S. 1920 Nutrient requirement of the potato plant grown in sand cultures treated with "type I" solutions. *In* Soil Sci., v. 10, p. 389–408.

(2) JOHNSTON, EARL S. 1924 Growth of potato plants in sand cultures treated with the "six types" of nutrient solutions. Md. Agr. Exp. Sta. Bul. 270.

(3) LIVINGSTON, B. E. (Editor) 1919 A Plan for Coöperative Research on the Salt Requirements of Representative Agricultural Plants, ed. 2. Div. Biol. and Agr. of Natl. Research Council, Baltimore.

(4) LIVINGSTON, B. E., AND TOTTINGHAM, W. E. 1918 A new three-salt nutrient solution for plant cultures. *In* Amer. Jour. Bot., v. 5, p. 337–346.

(5) MCCALL, A. G., AND HAAG, J. R. 1920 The hydrogen-ion concentration of certain three-salt nutrient solutions for plants. *In* Soil Sci., v. 10, p. 481–485.
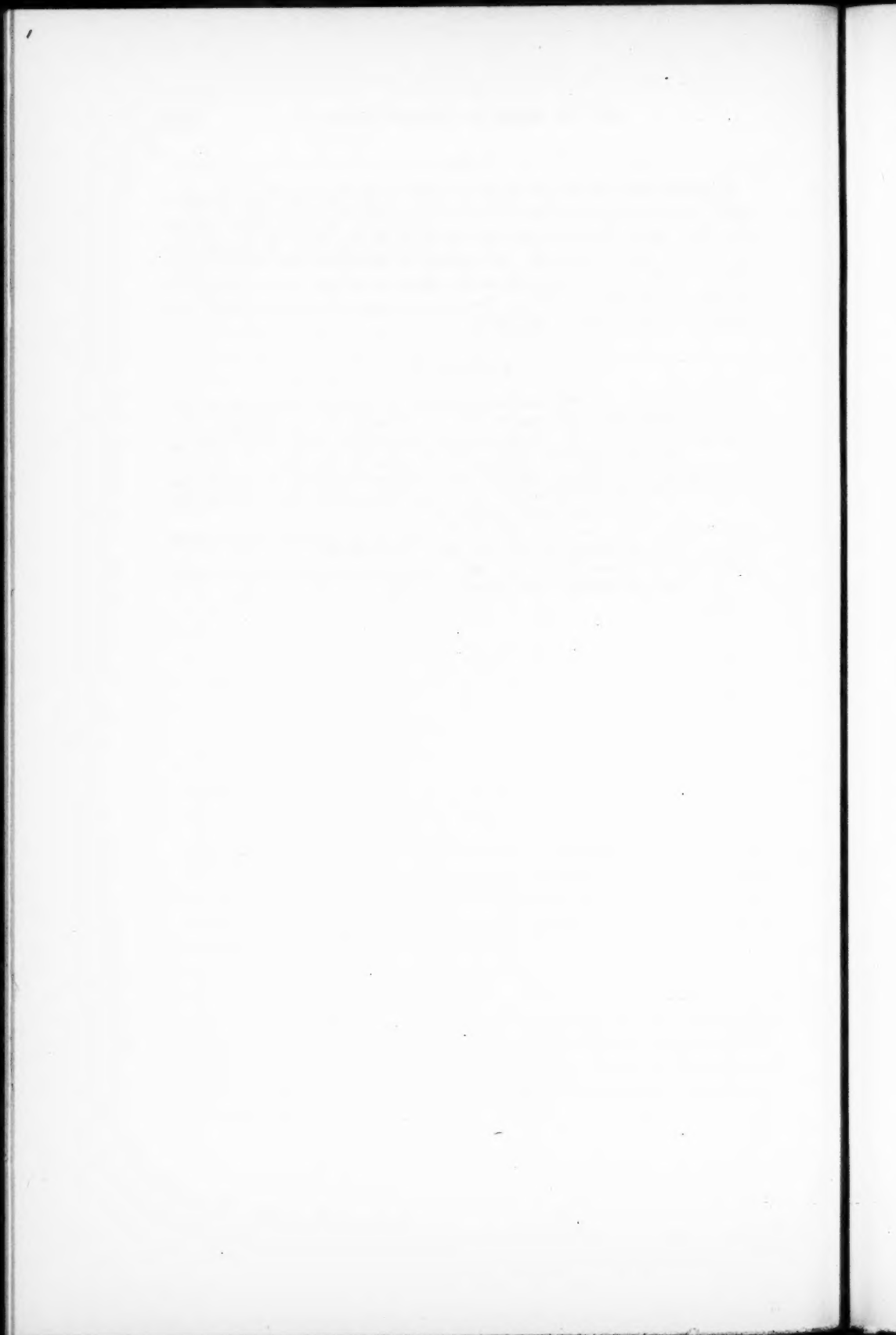
THE DISINTEGRATION OF LIMESTONE AND DOLOMITE SEPARATES AS INFLUENCED BY ZONE OF INCORPORATION[1]

W. H. MacINTIRE AND W. M. SHAW

University of Tennessee Agricultural Experiment Station

Among the factors which have to do with the efficiency of ground limestones, fineness is probably the most important. This factor enters into the economics of liming through home or community crushing and the usage of the commercial crushed product. The proper depth of incorporation within the soil is also a problem, concerning which there has been little investigation and some diversity of opinion.

Discussing the factor of fineness, Thomas and Frear (16) take the viewpoint that: "Crushed limestone worked into the soil probably exercises no influence upon the latter other than that which so much quartz sand or other inert material would have, so long as the limestone remains undissolved" and (5) "Limestone does not work until its decomposition occurs."

Concerning the second factor, depth of incorporation, Frear (4) advances the belief "that the surface soil is usually most in need of lime," and "it follows that lime intended for neutralizing the surface soil, should not be plowed under, because it does not rise easily; that lime intended for neutralizing the subsoil must be placed there directly; that lime intended for neutralizing the surface soil, must be thoroughly stirred through that soil by mechanical means, when the soil is dry enough to work."

This contribution represents a 4-year lysimeter study of:

(*a*) The disintegration of limestone and dolomite separates as influenced by the degree of fineness of the materials.

(*b*) The influence of zone of incorporation upon the extent of such disintegration.

HISTORICAL

We do not know of previous work in which the influence of zone of incorporation was included as one of the factors which influence the disintegration of limestones; but the influence of fineness upon disintegration and comparisons between limestone and dolomite separates have been reported upon by several investigators.

403

Ames and Schollenberger (1) examined field plots which had been treated with each of 4 separates and 2 mixtures. They found that the finer separates of both limestone and dolomite were more extensively decomposed and that the high-magnesian stone was the more resistant to the disintegrative action of the soil.

Broughton, Williams and Frazer (2) used 10,000-pound $CaCO_3$ treatments over a period of one year, in a study of the availability of ground limestone and oyster shells, by means of large pots equipped to yield leachings, the calcium content of which was taken as an index of carbonate decomposition. They concluded that relative decomposition is dependent upon fineness and that 80-mesh material can be considered as equivalent to burnt lime.

White (17) conducted a 3-year pot study, using 4 separates of both limestone and dolomite. Nitrification, diminution of acidity and decrease in carbonates were used as measures of carbonate decomposition. He concluded that 8-mesh material was quite inactive; that the 20-, 60- and 100-mesh separates increased in activity with fineness and that limestone was appreciably more reactive than dolomite. The conclusion was also drawn that, in practice, a mixture of separates should be used in preference to finely ground material.

Stewart and Wyatt (15) studied plots which had been treated nearly 4 years previously with limestone and dolomite of different degrees of fineness, the mechanical analyses of which were not given. They found the disintegration of limestone was more extensive than that of dolomite and advanced the apparently contradictory conclusions that dolomite ". . . . is slightly more effective than high-calcium limestone in neutralizing the soil acidity, is more durable, ..." They also concluded that "there is no evidence that finely ground limestone is more effective in correcting soil acidity than is the total product from a $\frac{1}{2}$-inch screen, which contains both the finer material for immediate use and the coarser material for greater durability."

Frear (4, 5) gave an extensive digest of the literature up to 1921 with photographs showing undisintegrated 0.5-mm. to 3-mm. fragments of limestone from those general fertilizer experiment plots which had received that treatment.

Morgan and Salter (14) used 2 soils, 12 limestones, and 12 dolomites in comparing the availabilities of 50-mesh and 100-mesh separates. Using reduction in acidity and decrease in residual carbonates as indices, they found the 100-mesh material to have been uniformly more active than the 50-mesh separates. They also found that the disintegration of limestone was more extensive than that of dolomite.

Kopeloff (7, 8) used 20–40, 60–80, 100–200 and < 200 separates is a study of influence of fineness upon availability in a number of soils. From decreases in lime requirement, as measured by the diminished ability of previously treated soils to liberate CO_2 from precipitated $CaCO_3$ additions, and from calcium content of leachings, it was concluded that increased decomposition of limestone treatments had occurred as the separates decreased in size.

In addition to the foregoing chemical studies, a number of investigations have been reported upon the response registered by plants, as indicating the greater solubility of the finer materials and in comparison between the values of the two forms of limestone.

EXPERIMENTAL

Equipment

The present study, begun May 1, 1921, represents one phase of an investigation carried out by means of the 34 field lysimeters illustrated in plates 1 and 2. Each unit consists of two close-fitting metal tanks of 14-gauge galvanized "Ingot" iron. The outer tank, resting upon a concrete base 2 feet square, is 2 feet deep and catches the leachings from the soil placed in the inner tank

which is 1 foot in depth.   The flat bottom of the outer tank slopes to a low point from which leads a vertical pipe culminating in a goose-neck through which the leachings are pumped, by means of a small electric motor, into containers in 4-unit groups.   The inner tank rests upon 3 heavy lugs, bradded and soldered against the inner wall of the outer tank.   A sloping collar at the top of the inner tank extends over the rim of the outer tank and prevents the influx of rain through the space between the sides of the nested tanks. Heavy loops are provided for the handling of the inner soil-filled tanks, which have concave bottoms with block-tin outlets leading from brass gauze strainers upon which rest 3-layer filters of gravel, coarse and medium sand, in order. The filter beds were of river material freed of lime by digestion with hydrochloric acid and thoroughly washed.   It was intended that the surface exposure of these tanks should be 1/20,000 acre, but as delivered the surface was equivalent to 1/21,043 acre.

Treatments and materials

The limestone and dolomite separates compared were 10–20-mesh, 20–40-mesh, 40–80-mesh, and 80–200-mesh, together with a composite made by taking one-fourth of the amount used for the full treatment of each of the 4 separates.   Eight tanks were used as controls: two tanks contained untreated soil, two contained hydrated lime, two contained calcined dolomite, and two contained CaO-MgO mixtures.

In determining the ability of the soil to decompose carbonate incorporations over a given period, the constant rate, or rates, of treatment should be less than the amount which the soil could absorb under the most favorable conditions.   The residual carbonates would thus range between zero and the residual from the most durable treatment.   This condition was insured in the present experiment, in which all treatments were equivalent to 2,000 pounds of CaO, or 3,570 pounds of $CaCO_3$, per 2,000,000 pounds of soil, moisture-free basis.

Different limestones have different cleavages, which may result in considerable variation in the surface areas of separates obtained from the same pair of sieves.   In an effort to minimize this difference, a more definite make-up of each unit was obtained by means of further subdivision.   The 10–20-mesh units contained 1,000-pound CaO-equivalences each of 10–15-mesh and 15–20-mesh separates.   The 20–40-mesh units received 1,000-pound equivalences each of 20–30-mesh and 30–40-mesh separates.   The 40–80-mesh units were made by use of 500-pound equivalences each of 40–50-, 50–60-, 60–70-, and 70–80-mesh separates.   The 80–200-mesh treatment contained equal amounts of 80–100-mesh and 100–200-mesh separates.   The composite treatments of both limestone and dolomite were made by mixtures of 250-pound CaO-equivalences each of 10–15- and 15–20-, 20–30- and 30–40-mesh separates, corresponding to 500-pound CaO-equivalences for both 10–20-mesh and 20–40-mesh units; 125-pound equivalences each of 40–50-, 50–60-, 60–70- and 70–80-

mesh separates, or 500-pound CaO-equivalences for the 40–80-mesh units and 250-pound equivalences each of the 80–100-mesh and 100–200-mesh sub-separates of the 80–200-mesh units.

The separations were made by means of sieves of decimal designation and conforming to Bureau of Standards and A. S. T. M. specifications. In each case the sieve of decimal designation most nearly corresponding to the ordinary unit designation for openings, was used. Differing from the ordinary sieves, those used are gauged by the actual measurement of the distance between the strands of each specific woven wire "cloth," so that any variation in diameter of the wire strands is not a factor in lineal measurement. The dimensions given for the several separates are, therefore, true and constant measurements.

After screening, and before analysis, each separate was thoroughly washed to remove any adhering limestone dust. The chemical equivalence for each separate and each control was then determined by boiling acid solution and back titration. The "complete" analysis of each separate was also made. The variations between the titration values and chemical analyses of the several separates of each limestone were not sufficient to warrant particular stress. The average compositions of the limestone and dolomite were found to be as follows.

	$CaCO_3$	$MgCO_3$	Fe_2O_3-Al_2O_3	SiO_2
	per cent	per cent	per cent	per cent
Limestone..................................	90.06	5.67	0.94	4.19
Dolomite	50.34	38.62	0.92	10.70

The calcined dolomite contained 46.53 per cent CaO and 32.85 per cent MgO.

In one series of tanks the incorporations were made in the upper half, or zone, of surface soil, without any treatment in the lower half. In the second series the incorporations were made in the lower half, or zone, whereas no treatment was given to the upper layer. The two layers were in intimate contact, but were well demarcated by an asphaltum-coated galvanized-iron wire disc of 1/8-inch mesh. Though considered on the basis of 2,000 pounds of CaO, or 3,570 pounds of $CaCO_3$ per 2,000,000 pounds of soil, the actual incorporation for each zone, or one-half of the full amount of soil, was on the basis of 1,000,000 pounds of soil. As the influence of the untreated zone cannot be divorced, however, from the treated zone, all results are calculated on the basis of the full soil depth.

Soil and analysis

The soil used had never been limed. It was a brown Cumberland loam, which contained 15.52 per cent of moisture when placed. The lower layer of soil rested directly upon the sand filter bed. No subsoil was placed under the surface soil because certain phases of the project called for the determination of the outgo from the surface soil and previous related work had shown

that the subsoil materially altered the salt-concentration of the leachings passing from the surface soil (11). In a 1:5 aqueous suspension the loam had an electrometric pH value of 6.23 for the control after 4 years' exposure, against a similar value of 6.38 for the sample that was reserved when the tanks were placed. Thorough screening, mixing, and conveyance to the tanks were done in one day. The pile of soil was closely covered during the overnight
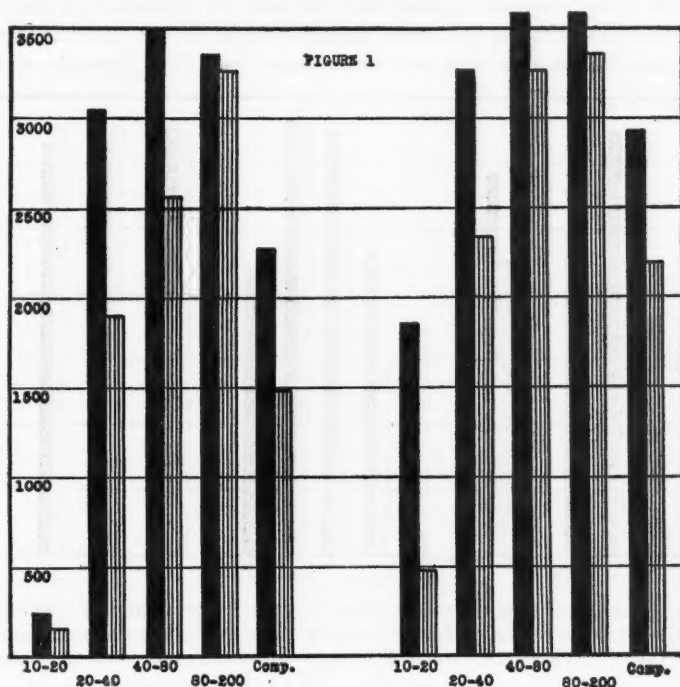
FIG. 1. COMPARATIVE DISINTEGRATIONS OF 2,000-POUND CaO, OR 3,570-POUND CaCO₃ EQUIVALENCES OF LIMESTONE AND DOLOMITE SEPARATES AND COMPOSITES PER 2,000,000 POUNDS OF SOIL, FROM SURFACE-ZONE AND SUBSURFACE-ZONE INCORPORATIONS IN LYSIMETERS, AFTER 4 YEARS' EXPOSURE

Solid black columns—limestone.
Ruled line columns—dolomite.

period of moisture determination. The limestone, dolomite and burnt-lime control additions were incorporated and the treated soils placed during the following forenoon. In loose tilth the total depth was approximately 8 inches and about 7 inches after compaction.

The tanks were kept free of plant growth, but the soil was never stirred. The periodic leachings were collected and analyzed for calcium and magnesium. These results will be given in a subsequent article.

Four years after treatments, the soil was removed from the tanks and all of that from each half, or zone, of each tank was thoroughly mixed. Four-quart samples were taken and immediately brought to an air-dry condition. After air-drying, the soil was reduced to 100-mesh fineness and charges of 100 gm. were used for the determination of residual carbonate-CO_2 by the method of MacIntire and Willis (10), using $1 + 4$ hydrochloric acid. The meagreness of some of the carbonate residuals and the need for representative samples made it desirable to use the largest workable charge for CO_2 determinations. The analytical charges were very much larger than those generally taken,
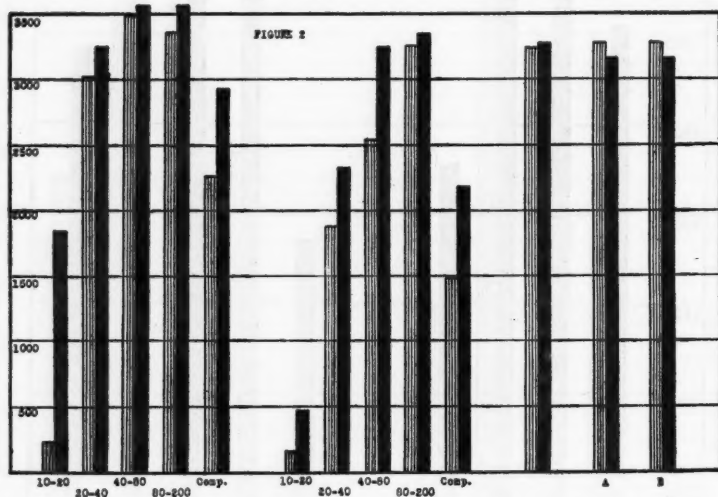
FIG. 2. INFLUENCE OF ZONE OF INCORPORATION UPON THE DISINTEGRATION OF 2,000-POUND
CaO OR 3,570-POUND CaCO$_3$ EQUIVALENCES OF LIMESTONE AND DOLOMITE SEPARATES
AND COMPOSITES PER 2,000,000 POUNDS OF SOIL—WITH BURNT LIME, BURNT DOLOMITE
AND CaO-MgO CONTROLS—IN LYSMETERS, AFTER 4 YEARS' EXPOSURE

Ruled line columns—surface-zone incorporations.
Solid black columns—subsurface-zone incorporations.
Burnt CaO-MgO: A—calcined dolomite; B—separately calcined CaO and MgO.

but the shaking apparatus used was designed especially to care for this factor. The carbonate-CO_2 results from the treated tanks were corrected by subtraction of the analytical blanks obtained from the no-treatment controls. These results are tabulated in table 1 and graphed in figures 1 and 2.

DISCUSSION OF RESULTS

Table 1 shows the ultimate disintegrations for all separates, as influenced by fineness and by zone of incorporation. The progressive speed of the carbonate decrease is not shown, because periodic soil samples of necessary bulk could not be taken without detrimental disruption of both zones. The

TABLE 1

Residual carbonates and disintegration of 2,000-pound CaO-equivalent limestone and dolomite separates* from surface-zone and subsurface-zone incorporations in an acid Cumberland loam after exposure in lysimeter tanks for a period of 4 years

SEPARATES INCORPORATED IN SOIL	CaCO₃—EQUIVALENT OF DETERMINED RESIDUAL CO2					RESIDUAL CaCO₃ CORRECTED FOR CONTROLS			DISINTEGRATION OF ADDITION BY DIFFERENCE AS ACCOUNTED FOR BY ABSORPTION AND LEACHING	
						On basis of moisture-free soil		On basis of addition		
	1	2	3	Average	Probable error	Analyses	Per 2,000,000 pounds			
	per cent	per cent	per cent	per cent	per cent	per cent	lbs.	per cent	per cent	lbs.
Group 1. From limestone incorporated in surface zone										
10–20 mesh..........	0.191	0.192	0.194	0.192	±0.001	0.167	3,340	93.5	6.5	230
20–40 mesh..........	0.051	0.051	0.053	0.052	±0.001	0.027	540	15.1	84.9	3,030
40–80 mesh..........	0.028	0.026	0.033	0.029	±0.002	0.004	80	2.2	97.8	3,490
80–200 mesh.........	0.031	0.040	0.034	0.035	±0.003	0.010	200	6.0	94.0	3,370
Composite†.........	0.094	0.082	0.094	0.090	±0.004	0.065	1,300	36.4	63.6	2,270
Group 2. From limestone incorporated in subsurface zone										
10– 20 mesh........	0.100	0.109	0.113	0.107	±0.004	0.086	1,720	48.2	51.8	1,850
20– 40 mesh........	0.038	0.038	0.039	0.038	±0.001	0.017	340	9.5	90.5	3,230
40– 80 mesh........	0.022	0.023	0.019	0.021	±0.001	0.000	000	0.0	100.0	3,570
80–200 mesh........	0.020	0.020	0.022	0.021	±0.001	0.000	000	0.0	100.0	3,570
Composite†.........	0.056	0.056	0.053	0.055	±0.001	0.034	680	19.0	81.0	2,890
Group 3. From dolomite incorporated in surface zone										
10– 20 mesh........	0.220	0.214	0.231	0.222	±0.005	0.197	3,940	110.3	(4.3)‡	(154)‡
20– 40 mesh........	0.113	0.108	0.116	0.112	±0.002	0.087	1,740	48.7	51.3	1,830
40– 80 mesh........	0.069	0.083	0.077	0.076	±0.004	0.051	1,020	28.6	71.4	2,550
80–200 mesh........	0.033	0.041	0.033	0.036	±0.003	0.015	300	8.4	91.6	3,270
Composite†.........	0.123	0.131	0.133	0.129	±0.003	0.104	2,080	58.2	41.8	1,490
Group 4. From dolomite incorporated in subsurface zone										
10– 20 mesh........	0.162	0.179	0.188	0.076	±0.008	0.155	3,100	86.8	13.2	470
20– 40 mesh........	0.072	0.088	0.091	0.083	±0.006	0.062	1,240	34.7	65.3	2,330
40– 80 mesh........	0.032	0.036	0.044	0.037	±0.003	0.016	320	9.0	91.0	3,250
80–200 mesh........	0.033	0.033	0.029	0.032	±0.001	0.011	220	6.2	93.8	3,350
Composite†.........	0.089	0.089	0.094	0.091	±0.002	0.070	1,400	39.2	60.8	2,170

* Constant of 2,000-pound CaO, or 3,570-pound CaCO₃ equivalences per acre.

† Equal quantities of 10–20-, 20–40-, 40–80- and 80–200- mesh separates.

‡ Using ratio of 41.8 and 63.6 of dolomite and limestone composites.

TABLE 1—*Continued*

SEPARATES INCORPORATED IN SOILS	CaCO₂—EQUIVALENT OF DETERMINED RESIDUAL CO₂					RESIDUAL CaCO₂ CORRECTED FOR CONTROLS			DISINTEGRATION OF ADDITION BY DIFFERENCE AS ACCOUNTED FOR BY ABSORPTION AND LEACHING	
						On basis of moisture-free soil		On basis of addition		
	1	2	3	Average	Probable error	Analysis	Per 2,000,000 pounds			
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*lbs.*	*per cent*	*per cent*	*lbs.*
Group 5. From burnt lime controls in surface zone										
CaO..............	0.041	0.041	.....	0.041	....	0.016	320	9.0	91.0	3,250
CaO–MgO§........	0.037	0.041	.....	0.039	....	0.014	280	7.8	92.2	3,290
CaO–MgO‖........	0.037	0.041	.....	0.039	....	0.014	280	7.8	92.2	3,290
Group 6. From burnt lime controls in subsurface zone										
CaO..............	0.038	0.031	.....	0.035	....	0.014	280	7.8	92.2	3,290
CaO–MgO§........	0.041	0.041	.....	0.041	....	0.020	400	11.2	88.8	3,170
CaO–MgO‖........	0.041	0.041	.....	0.041	....	0.020	400	11.2	88.8	3,170
Group 7. From untreated controls										
Surface............	0.026	0.026	0.024	0.025	±0.001	.....	.....	.....	....	....
Subsurface.	0.020	0.019	0.025	0.021	±0.002	.....	.....	.....	....	....

§ Burnt dolomite.
‖ Mixture of separately calcined oxides.

amounts of added carbonates which have disappeared through the combined causes of fixation and leaching are determined by difference.

In considering the analytical data it should be remembered that the small variation of 0.01 per cent in the treated soil is the equivalent of 200 pounds when applied to the 2,000,000-pound soil basis and that this is magnified to 5.6 per cent when expressed as a fraction of the constant 3,570-pound CaCO₃-equivalent incorporations.

Since there was no mechanical disturbance of the soil during the 4-year period, it is concluded that any removal of carbonates from the surface zone was due solely to solution and leaching. The untreated subsurface zone was examined for any particle of limestone which might have migrated from the upper treated zone, but no evidence of such migration was found.

Comparison of limestone separates

The data of the first, or surface zone, group show that only 230 pounds of the 10–20-mesh separate has been changed from the carbonate form during 4

years, whereas 3,030 pounds, or 84.9 per cent, of the 20–40-mesh addition has been transformed.   From the 40–80-mesh and 80–200-mesh separates, only 80 pounds and 200 pounds, respectively, remained at the close of the experiment.   In the case of the composite, which may be assumed to be fairly representative of a 10-mesh product, 63.6 per cent of the addition, or 2,270 pounds had been disintegrated.   It may be assumed, for all practical purposes, that the 40–80-mesh and 80–200-mesh separates had been completely decomposed, since they showed disintegration fully equivalent to that found for each of the three lime controls; but, as will be considered later, it is possible that the small apparent residuals are true residues.

In the second, or subsurface group, 51.8 per cent, or 1,850 pounds, of the 10–20-mesh separate and 90.5 per cent, or 3,230 pounds, of the 20–40-mesh separate had been disintegrated; but all of the 40–80-mesh and 80–200-mesh materials had been decomposed.   Of the equal-part composite 2,890 pounds, or 81 per cent, had been disintegrated.   The same general relationship found in group 1, as to influence of fineness upon extent of disintegration, is found to exist for the several separates of this group.

Comparison of dolomite separates

In the third group, the surface-zone residual carbonates from the dolomite separates show progressive decrease in carbonate residuals and progressively increased disintegration for the 20–40-mesh, 40–80-mesh, and 80–200-mesh additions.   The 80–200-mesh material gave results practically the same as those from the three burnt lime surface-zone controls.

An increase over theory shows in the case of the 10–20-mesh units where a plus figure of 10 per cent was obtained.   The analytical data and the calculations for this treatment were both verified.   It could not be held that lack of uniform incorporation and a resultant misrepresentative sample were responsible for the discrepancy, because when the tanks were disrupted the soil was again thoroughly mixed and sampled.   The only plausible explanation, therefore, would seem to be that a plus error was made in the weighing of one or both of the particular sub-separates of this addition.   In the light of the uniformity shown in the several comparisons between limestone and dolomite, it is certain that the disintegration of this separate was less than the 6.5 per cent, or 230-pound, disintegration found in the 10–20-mesh limestone treatment.   It would seem justifiable, therefore, to assume the figure of 4.3 per cent, or 154 pounds, for the 10–20-mesh separate of the more insoluble dolomite.   This proportion of 4.3 per cent to 6.5 per cent for disintegrations of the 10–20-mesh dolomite and limestone separates is equivalent to that of 41.8 to 63.6 per cent, the determined disintegration ratio between the dolomite and limestone composites.

In the fourth group, dolomite in subsurface, the 10–20-mesh separate shows a loss of only 470 pounds from the original 3,570-pound $CaCO_3$-equivalence, whereas the 20–40-mesh unit shows a much greater disintegration, 2,330

pounds. The 40–80-mesh and 80–200-mesh units showed decompositions of 3,250 pounds and 3,350 pounds, respectively, both figures being slightly greater than those from the burnt CaO-MgO controls. The composite for this group shows a loss of 2,170 pounds, corresponding most nearly to that of the 20–40-mesh separate.

Limestone-dolomite comparisons

In all comparisons between each corresponding pair of limestone and dolomite separates, the limestone was more extensively disintegrated, especially for the less extensively decomposed coarser separates and in the surface zone. The graphic relationships between the two limestones are given in figure 1. A grand average of 2,750 pounds was obtained from the 10 limestone units, against 2,086 pounds for the 10 dolomite units. This is in conformity with the accepted fact that *true* limestones are more soluble than *true* dolomites. It is in harmony with the conclusions given in all citations, save the one of Stewart and Wyatt (15). It does not conflict with the previous supplementary finding from this Station (10), where equal and heavy additions of limestone and dolomite gave practically identical residues; nor with the 5-year leaching data (12), which showed near-equal solubility, as measured by losses of Ca-Mg from equivalent amounts of the two limestones. In the former case the limestone and dolomite treatments were equivalent to 16,000 pounds of CaO per 2,000,000,000 pounds of soil, or eight times the present basis, and the finely divided portions of both ground rocks were sufficient to neutralize the more acid-reactive soil components. In the latter case, the 2,000-pound CaO-equivalent treatments of both limestone and dolomite were of less than 100-mesh fineness. Furthermore, the intensity of treatment was only one-half that of the present experiment, for the added materials were disseminated throughout twice the volume of soil and the full applications were absorbed by, or leached from, the soil.

The larger differences between the amounts of limestone and dolomite disintegrated were found where the coarser materials were used. With increase of surface, the ultimate decompositions of the dolomite separates approached those of the corresponding limestone separates. Both of the finest limestone separates had entirely disappeared from the subsurface zone, and an average of 96 per cent of the same two separates had disappeared from the surface zone. Of the dolomite disintegration 93.8 per cent and 91.6 per cent occurred in the case of the 80–200-mesh dolomite separate for the subsurface and surface zones, respectively. Disintegrations of 91 per cent and 71.4 per cent were obtained from the corresponding surface-zone incorporations. These figures indicate that with the second finest material, 40–80-mesh, both reactive surface and zone of incorporation are important factors in determining the value of a particular separate.

It is doubtless true that the extensive disintegration of the two finest separates of both materials had been brought about in most part long before the

end of the 4-year experimental interval. In the case of the 80–200-mesh separates, it would be conservative to say that the residuals after one to two years would have been practically the same as those at the end of the fourth year. This reasoning is based upon other data from the same soil and materials, at the same rate, for the full soil depth over a 5-year period, during which the outgo of calcium-magnesium from a 2,000-pound CaO-equivalence of limestone was practically the same as that from dolomite, while the agreement was also close for the first and second annual periods. But in the earlier 5-year experiment, previously reported (12), the 100-mesh materials were mixed through the entire depth of soil. If, to offset this difference as to method of incorporation, it be assumed that zone incorporations required twice the time needed for complete disintegration of full-depth incorporation, it seems reasonable and conservative to conclude that the complete decomposition of carbonate found for the experimental period of 4 years would have been in effect also at the end of the first 2 years.

Surface versus subsurface incorporations

In considering the question of depth of incorporation under humid conditions there arise two factors: (a) difference between the speed of disintegration through solution and fixation and (b) subsequent retention in the different soil layers. The viewpoint which advocates surface incorporation of lime is based upon the assumption that lime readily moves downward and that any subsurface need will be cared for by such movement. The contention for deep incorporation is based upon the belief that movement is limited and that mechanical distribution is necessary when lime is needed in the lower tillable zone. Related lysimeter work (11) has demonstrated that large amounts of soluble salts of calcium and magnesium are stopped by the clay subsoil found in place under the loam soil used in this experiment. It seemed quite reasonable to assume that, in lesser degree, an untreated and unsaturated zone of surface soil would function in the same manner. Since the present experiment was carried out in lysimeters, both of these factors were subject to determination, but this paper deals solely with the carbonate residues as an index of disintegration.

Graphic comparisons between groups 1 and 2, 3 and 4, and 5 and 6 of table 1 are given in figure 2. Without exception, the subsurface limestone and dolomite incorporations have undergone more extensive disintegration. The disparity is especially marked in the case of the coarser separates and in the composite treatments. The disintegration of the 10–20-mesh limestone in the subsurface zone was 8 times that brought about in the surface zone. The carbonate disappearance was complete in the case of the 2 finer separates of limestone in the subsurface and practically so in the surface zone. This greater decomposition in the lower zone may be due to several causes. The subsurface zone is generally more moist than the surface and better opportunity for solution is thus afforded. Furthermore, the free-soil water of the

lower zone was, in all probability, uniformly more heavily charged with CO_2, for Brown (3) and King and Doryland (6) have shown that bacterial activities responsible for CO_2 production may be more extensive in the second 4 inches than in the upper 4-inch zone. Then too, the free water of the untreated surface zone has only the more resistant native calcium and magnesium to draw upon. It therefore reaches the subsurface zone unsaturated with bicarbonates and with an excess of dissolved free CO_2, which, through formation of bicarbonates, augments the solution of the lower-zone limestones.

With greater decomposition, it would be expected that greater absorption and retention would also be in effect. This sequence does not necessarily obtain under the experimental conditions imposed in this study. The free water from the subsurface-zone treatments passed directly through the non-absorbing sand filters, whereas that from the surface-zone treatments had to pass through the unsaturated layer of surface soil. This variability phase of the subject will be considered in another paper.

In comparing surface incorporations of the finest limestone separates against the high-calcic burnt-lime controls, incorporated as hydrate, and subsurface-zone incorporations of the same materials, theoretical carbonation is assumed for the unabsorbed and unleached fractions of both $Ca(OH)_2$ and CaO-MgO under the experimental conditions. This assumption is justified by previous studies (9, 13). But in the present study it appeared that there was some residual carbonate from the burnt-lime control, though none from the finer limestone separates in the subsurface zone. The carbonate residual in the surface zone was also greater for the burnt lime than for the finer limestone separates. It would appear, therefore, that the finest limestone separates had been more extensively absorbed. The same observation obtains when the 80–200-mesh dolomite separate is compared with the two burnt CaO-MgO controls for both zones of incorporation. But, since the finely divided carbonates derived from $Ca(OH)_2$ and CaO-MgO are much more soluble than the finest subdivisions of limestone, which was completely decomposed, and the less soluble dolomite, which was almost completely decomposed, it would seem that the small differences, if actual rather than apparent, are to be attributed to the mechanics of incorporation. The finest limestone and dolomite separates were thoroughly disseminated throughout the soil without any noticeable lumping. On the other hand, the hydrates and oxides had some tendency to lump, both while stored as samples after sieving and during incorporation with the moist soil. Any lumps formed during admixing may become coated with soil and obscured, so that it is difficult to obtain the same uniform distribution which is possible with the limestone separates. When the soils were finally dried and prepared for CO_2 analysis, after 4 years of exposure, some of these small lumps were still discernible. It is quite possible, therefore, that the small differences obtained in residual carbonate CO_2 may be actual and attributable to this factor. Nevertheless, the differences between the 80–200-mesh separates and the hydrate and oxide controls are so small as to be

primarily of academic interest, and for all practical purposes the carbonate and burned products may be considered as being of identical and absolute availability.

SUMMARY

Four limestone separates and a composite, all equivalent to 2,000 pounds of CaO, or 3,570 pounds of $CaCO_3$, per 2,000,000 pounds of soil were compared with corresponding dolomite treatments—hydrated lime, burnt dolomite, and CaO-MgO mixtures being used as controls—in a 4-year lysimeter study of availability as measured by ultimate carbonate disintegration and as influenced by (a) *fineness* and (b) *zone of incorporation*.

The 10–20-mesh limestone separate underwent slight change in the surface zone. About 85 per cent of the 20–40-mesh material was decomposed, whereas practically all of both 40–80-mesh and 80–200-mesh materials was disintegrated. The equal-part composite approached most closely the value found for the 20–40-mesh separate.

The disintegration of the coarsest limestone separate in the subsurface zone was eight times that in the surface zone. All the other separates likewise showed greater decomposition in the lower soil layer.

The dolomite separates showed the influence of fineness upon ultimate decomposition, with maximum for the 80–200-mesh, the composite showing closest agreement with the 20–40-mesh material.

Each limestone separate showed greater decomposition than the corresponding dolomite separate for both surface and subsurface incorporations. The coarser the separates, the more marked was the disparity.

For all practical purposes, it may be said that both limestone and dolomite of 80–200-mesh fineness were completely disintegrated in both surface and subsurface zone; but that for the coarser separates the variables of greater solubility of limestone and the more favorable conditions of the subsoil zone were factors which definitely delimited the extent of disintegration.

REFERENCES

(1) AMES. J. W., AND SCHOLLENBERGER, C. J. 1916 Liming and lime requirement of soil. Ohio Agr. Exp. Sta. Bul. 306, p. 300–303.

(2) BROUGHTON, L. B., WILLIAMS, R. C., AND FRAZER, G. S. 1916 Tests of the availability of different grades of limestone. Md. Agr. Exp. Sta. Bul. 193.

(3) BROWN, P. E. 1912 Bacteria at different depths in some typical Iowa soils. Iowa Agr. Exp. Sta. Res. Bul. 8.

(4) FREAR, WM. 1915 Sour soils and liming. Pa. Dept. Agr. Bul. 261, p. 135, 213.

(5) FREAR, WM. 1921 The fineness of lime and limestone application as related to crop production. *In* Jour. Amer. Soc. Agron., v. 13, p. 179.

(6) KING, W. E., AND DORYLAND, J. T. 1909 The influence of depth of cultivation upon soil bacteria and their activities. Kans. Agr. Exp. Sta. Bul. 161, p. 213–215.

(7) KOPELOFF, N. 1917 The effect of fineness of division of pulverized limestone on the yield of crimson clover and lime requirements of soils. *In* Science, n.s., v. 55, no. 1163, p. 363–365.

(8) Kopeloff, N. 1917 The influence of fineness of division of pulverized limestone on crop yield as well as the chemical and bacteriological factors in soil fertility. *In* Soil Sci., v. 4, p. 19–71.

(9) MacIntire, W. H. 1919 The carbonation of burnt lime in soils. *In* Soil Sci., v. 7, p. 325–453.

(10) MacIntire, W. H., and Willis, L. G. 1915 The determination of soil carbonates— A modification. *In* Jour. Indus. Engin. Chem., v. 7, p. 228.

(11) MacIntire, W. H., Shaw, W. M., and Young, J. B. 1923 The variant rôles of soil and subsoil in calcium-magnesium interchange. *In* Soil Sci., v. 16, p. 339.

(12) MacIntire, W. H., Shaw, W. M., and Young, J. B. 1923 Reciprocal repression exerted by calcic and magnesic additions upon the solubility of native materials in surface soil. *In* Soil Sci., v. 16, p. 449–464.

(13) MacIntire, W. H., Shaw, W. M., and Young, J. B. 1925 The rôle of silica in counteracting magnesia-induced toxicity. *In* Soil Sci., v. 19, p. 331–341.

(14) Morgan, M. F., and Salter, R. M. 1923 Solubility of limestones as related to their physical properties. *In* Soil Sci., v. 15, p. 293–305.

(15) Stewart, R., and Wyatt, F. A. 1919 The comparative value of various forms of limestone. *In* Soil Sci., v. 7, p. 273–278.

(16) Thomas, W., and Frear, Wm. 1912 Experiments to determine the influence of the fineness of subdivision and richness in magnesium carbonate of crushed limestone used for amendment of acid soils. *In* Pa. Agr. Exp. Sta. Ann. Rpt., 1912–1913, p. 206.

(17) White, J. W. 1917 The value of limestone of different degrees of fineness. Pa. Agr. Exp. Sta. Bul. 149.

PLATE 1

Fig. 1. Double-tank lysimeters with one inner tank exposed.
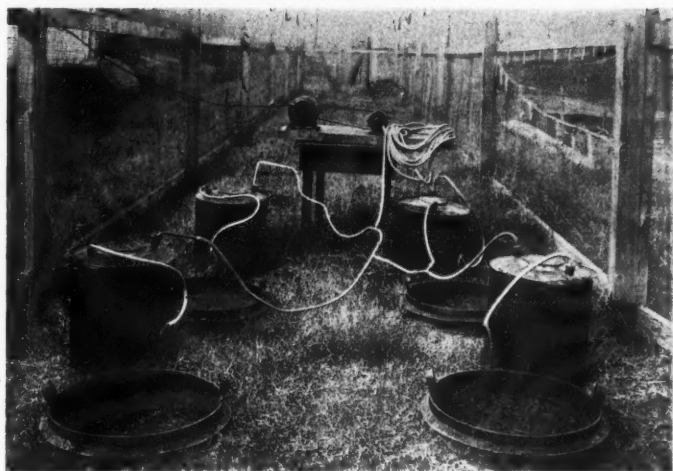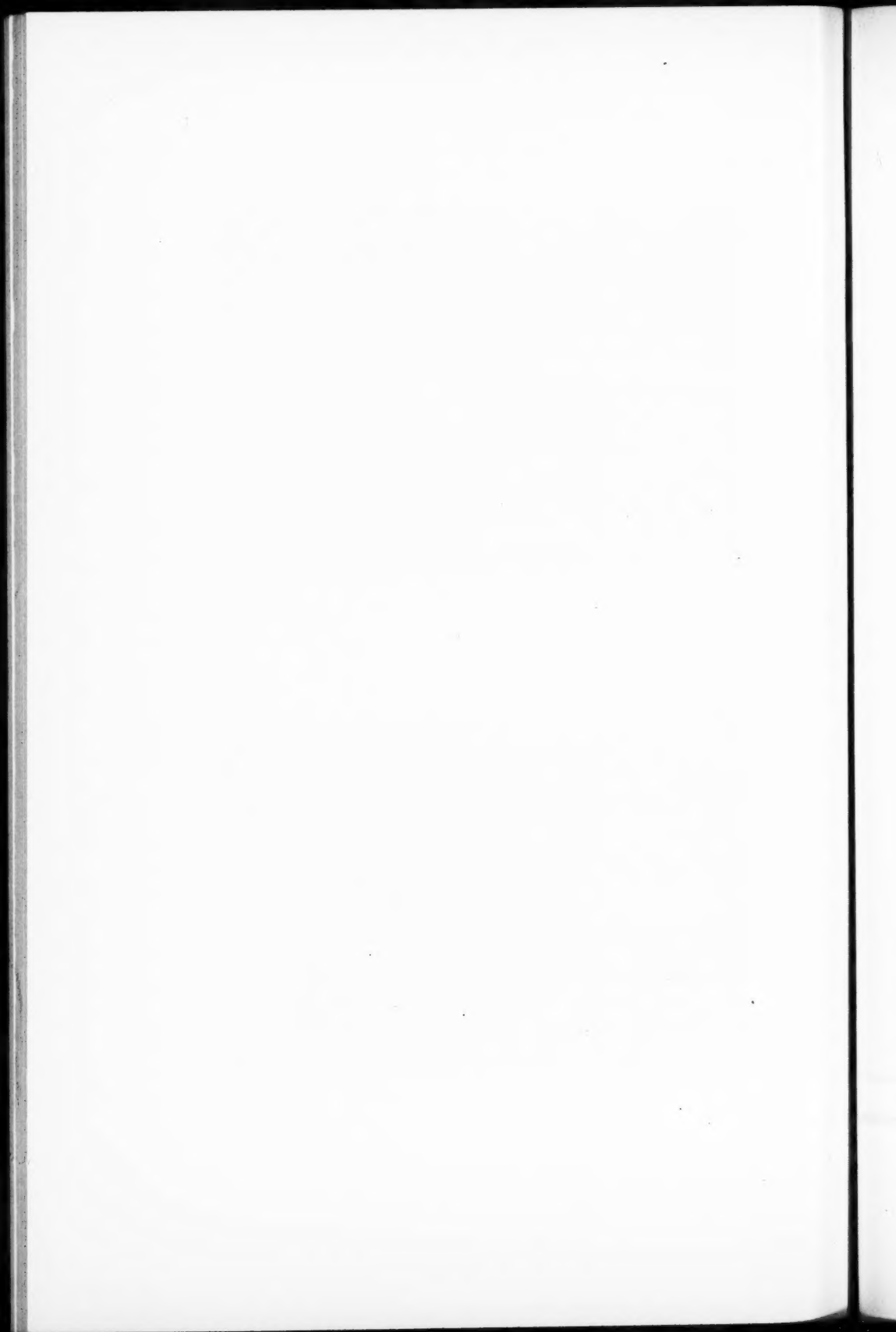Fig. 2. Arrangement for collection of leachings from double-tank lysimeters.

FIG. 1

FIG. 2

417

TWO UNUSUAL COLLOIDAL SOILS[1]

CHARLES F. SHAW

University of California

Within the past two years, the writer has encountered two colloidal soils of extreme and striking character; gelatinous when wet, horny when dry, with a very low volume weight, enormous water holding capacity, high moisture equivalent, and a high degree of shrinkage on drying and of expansion on wetting.

The first is a subsoil from a sugar cane field on Olaa plantation, on the windward slopes of the island of Hawaii, about half way between Hilo and the volcano of Kilauea. The soil is apparently residual in origin, very deeply weathered, and derived from a secondary mudflow originating in the lavas from Mauna Loa. In nature it had supported a low, dense growth of bushes and vines. It has been cleared and planted to cane with indifferent results. Drainage conditions which were the immediate cause of the visit, appeared to be poor. The soil sample was taken from the vertical side of a ditch bank, and although decidedly moist, contained no free water.

The second soil was found a few months later in the recently exposed bed of Lower Klamath Lake on the California-Oregon line. The surface of the lake bed was dried out to a depth of about one foot, and consisted of chunks, slivers and clods of a hard, horny gray material of very light weight. Beneath this the material resembled gelatin in consistency; the upper, drier portion being somewhat elastic and cheesy, and the deeper portions very soft.

SOIL MOISTURE

The moisture was determined by drying for from two to five days in an electrically heated oven at a controlled temperature of 100°C. The sample from Olaa had been sealed in a glass jar and shipped to Berkeley. A crude test at the time the sample was taken showed about 400 per cent moisture, calculated on the dry basis, and a more careful determination a few days later, at the laboratories of the Sugar Planters' Experiment Station at Honolulu showed about 375 per cent. The tests in Berkeley were made about one year after the samples had been taken.

The samples from Lower Klamath Lake were from different parts of the lake bed and contained different amounts of water when sampled. Due to unavoid-

---

[1] Approved for publication, June 20, 1925, by Director E. D. Merrill of the California Agricultural Experiment Station.

ably rough handling and the lack of water-tight containers, considerable mois-
ture must have been lost during the five days that elapsed between the time of
sampling and the time the first moisture determinations were made (table 1).

Although the amounts of water present in these soils are extremely high,
no water would seep or drain from any of them in the field.   When squeezed
in the hands or in canvas sacks, water could be expressed, but on releasing the
pressure much of it would be re-absorbed.   The amounts present apparently
are below the maximum moisture capacity of these soils.

When the field-dry, horny fragments were allowed to absorb water, they
expanded in bulk very decidedly, absorbing from 135 to 140 per cent of mois-
ture (dry basis) when the lumps were used, and from 155 to 175 per cent when
granular material was used.

TABLE 1

Soil moisture

SOIL	WEIGHT OF SOIL		LOSS	MOISTURE	
	Wet	Dried		Wet basis	Dry basis
	gm.	*gm.*	*gm.*	*per cent*	*per cent*
Olaa...............................	39.88	9.40	30.48	76.42	324.25
Lower Klamath 8A.................	6.16	5.68	0.48	7.79	8.44
Lower Klamath 8B.................	47.52	15.00	32.52	68.43	216.80
Lower Klamath 8BD..............	4.66	4.31	0.35	7.51	8.12
Lower Klamath 10B................	47.11	7.36	39.75	84.37	540.08
Lower Klamath 11A................	8.82	2.58	6.24	70.74	241.86
Lower Klamath 11B................	16.72	7.15	9.57	57.15	133.84

Olaa—a subsoil of an elastic, cheesy character.
8A—dried lake bed surface, of tough, horny character.
8B—elastic, cheesy clay subsoil of 8A.
8BD—duplicates of 8B after several months of air-drying, included in table for comparison.
10B—gelatinous subsoil, unstable but sufficiently stiff to maintain vertical walls of hole.
11A—fibrous black peat, well decomposed, margins of lake.
11B—bluish, tough, rubbery clay, subsoil of 11A.

VOLUME WEIGHT DETERMINATIONS

The volume weight determinations were made on portions of soil 8B that
had been held in the laboratory for some weeks in sealed jars.   An arbitrary
method had to be devised, as the soil was in fragments that had the resiliency
and consistency of a very elastic cheese.   Aluminum dishes 5 cm. in diameter
and 1.5 cm. deep were used, the soil being pressed into them with a sliding
motion in order to break down the granules.   Every effort was made to pack
the maximum amount of the moist soil into the dishes.   The soils were dried
for four days at 95°C. and for 14 hours at 115°C.   In table 2, the volume weight
is given both on wet weight basis and on dry weight basis.   The percentage of
water, dry basis, is also given.

In view of the crudeness of the method, the results are surprisingly close.

The volume weight on the dry basis is not fair, as the soil on drying shrunk materially. It cracked so badly that no volume measurements could be made, but rough tests indicated a volume weight just below 1. The fragments would float in water for a time; then as they became moist, would slowly sink.

LOSS ON IGNITION

Loss on ignition was determined for soils Olaa, 10B and 8B, the oven-dry soil from the volume weight and soil moisture tests being used. The soils

TABLE 2

Volume weight

SOIL	WEIGHT OF SOIL		LOSS WATER	WATER DRY BASIS	VOLUME DISH	VOLUME WEIGHT	
	Wet	Dry				Wet	Dry
	gm.	gm.	gm.	per cent	cc.	gm.	gm.
8B-1..................	29.06	10.29	18.77	182.43	27.00	1.075	0.381
8B-2..................	29.47	9.81	19.66	200.40	26.60	1.107	0.368
8B-3..................	30.62	10.47	20.15	192.45	27.10	1.130	0.382
8B-4..................	30.62	10.27	20.35	198.15	27.30	1.121	0.376
8B-5..................	28.08	9.93	18.15	180.73	24.80	1.132	0.360
8B-6..................	29.09	10.63	18.46	173.66	27.20	1.065	0.390
Average...				187.97		1.105	

TABLE 3

Loss on ignition

SOIL	WEIGHT OF SOIL		LOSS	
	Before igniting	After igniting		
	gm.	gm.	gm.	per cent
Olaa............................	4.07	2.79	1.28	31.2
10B............................	2.10	1.43	0.77	38.0
8B-1.........................	2.95	1.74	1.22	41.3
8B-2.........................	3.17	1.63	1.54	48.5
8B-3.........................	3.85	1.76	2.09	54.2
8B-4.........................	2.91	1.33	1.58	54.2

were ignited in crucibles over a bunsen flame until the smoke and readily volatile material had disappeared, then heated in a blast to white heat. The percentage of loss is calculated on the basis of the original oven-dry weight of the sample.

The average for the four determinations on 8B is 49.55. The volatile matter for this soil as reported by Dr. Kelley (see table on page 422), is 47.41, a fairly close agreement.

MOISTURE EQUIVALENT

Unsuccessful attempts were made to disperse this soil mechanically by prolonged shaking. The material was too light and too resilient to break up, even when hard rubber stoppers were introduced to help grind it. After these attempts were abandoned, a considerable quantity was covered with distilled water, sealed in a glass jar and allowed to stand, with occasional shaking, for over eight months. It developed a strong offensive odor and the material was partly dispersed as a thin mud, with numerous lumps and chunks, rather elastic, but which could be easily broken. Moisture equivalent determinations were made by pouring this material into the centrifuge cups, filling them about three-fourths full. The excess water was allowed to drain away and the mass was pressed down slightly to express the surplus water. When removed from the centrifuge the moist soil was approximately one centimeter deep, but on drying it shrunk to about one-half the original bulk. The dry soil proved to be of only about one-fifth the weight usually used.

TABLE 4

Moisture equivalent

SOIL	WEIGHT OF SOIL		LOSS	MOISTURE EQUIVALENT
	Wet	Dry		
	gm.	gm.	gm.	
8B-1	33.11	6.90	26.21	380.00
8B-2	32.58	6.72	25.86	384.82
8B-3	32.26	6.86	25.40	370.10
8B-4	30.55	6.81	23.74	348.00

The average moisture equivalent is 370.73 for the four replicates, or 378.3 if only the first three are considered. The lumpy consistency of the soil when placed in the cup readily accounts for the range in the results obtained.

CHEMICAL COMPOSITION

A chemical analysis of this material was made by Dr. W. P. Kelley of the Citrus Experiment Station, who reports the following composition:

SiO_2 .... 39.89
Al_2O_3 .... 4.66
Fe_2O_3 .... 1.23
SO_4 .... 0.67
Ca 3.00
Mg 0.62
K 0.33
Na 0.62
    Volatile matter 47.41
                                                    ———
                                                    98.43

It should be stated that this analysis is not quite complete as there are small amounts of constituents not determined. We know, for example, that this material contains a small amount of carbonate, probably calcium carbonate; but calculating the results on the organic-matter-free-basis, you will observe that the inorganic matter is composed very largely of silica.

The Olaa material is formed by residual weathering of basic lavas under conditions of high precipitation and of high temperatures, which promote continued and rapid leaching throughout the whole period of its formation. It has occasioned much difficulty with drainage and irrigation; crop growth is poor and yields unsatisfactory.

The Klamath Lake soil is the bed of Lower Klamath Lake made dry by shutting off the main source of water supply. This lake has never received much sediment, as most suspended material is deposited in the Upper Lake. Investigators who were on the lake before it became dry have reported the lake bottom to be a "sludge" of considerable depth. This "sludge" is now the lake bed soil herein described. The microscope shows that it is composed largely of the remains of diatoms, and probably was formed as a thick layer of diatomaceous colloidal silica in the lake bottom, the first stage in formation of "diatomaceous earth." The material has not been weathered, as in the case of that at Olaa, but is a recently exposed deposit wholly unaltered by weathering activities.

The lake bed is proposed for reclamation, subdivision, and close settlement. It is obvious that the soil will prevent grave and unusual difficulties if an attempt is made to farm it, or to accomplish adequate drainage or suitable irrigation. The water-holding capacity is enormous, but the water available to plants may be relatively very little. Successful agriculture on such soil is decidedly improbable.

SUMMARY

Samples of colloidal soil materials from the island of Hawaii and from the dried bed of Lower Klamath Lake, on the Oregan-California line, show very unusual physical properties.

Soil moisture in the field condition varied from 133.84 to 540.08 per cent without seepage. Air-dried samples contained from 8 to 10 per cent moisture. The moisture equivalent of the Klamath soil was from 348 to 380; the volume weight of the field soils average 1.105 on the wet basis, whereas the dry soil is lighter than water, and will float.

Loss on ignition showed volatile material as 31.2 per cent of the Olaa soil and from 38 to 54 per cent of the Klamath soil; the chemical analysis showed the inorganic matter to be composed largely of silica, with nearly half the total material volatile.